

Observational activities



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Summary

This booklet will provide you with an overview of the S282 observational activities and give you some necessary background information. It includes a description of how to find objects in the sky through the use of astronomical coordinate systems and a planisphere, how to plan and perform observations, analyse your data and present your results in a write-up.

Instructions for five specific activities are given at the end of this booklet. (They are also available as individual PDF files on the course website.) After you have read this booklet you should view the video sequence 'Preparing for observing' which is devoted to the observational activity work.

The S282 observational activity work is based on your own observations. No previous experience is necessary, and the observations are correspondingly basic. However, they are by no means trivial: not only do they serve to familiarize you with some of the fundamental features of our view of the cosmos, but they also enable you to develop a range of skills of general usefulness and applicability, notably:

- practical skills – through planning and making the observations
- data-handling skills – through displaying and analysing data derived from the observations
- scientific methodology skills – through comparing observations of data with accepted models, and through predicting the outcome of future observations
- communication skills – through writing activity reports.

All of the activities involve observations, and some of them involve the use of binoculars. However, if you do not have ready access to binoculars, and do not wish to obtain any, then be assured that it will be possible to complete the activities to an adequate level with the naked-eye.

To make the observations you will need clear skies for only half an hour or so on each of four or five separate days. However, you should endeavour to make your sky observations as soon as you can – it is possible for there to be a run of several weeks with barely a break in the clouds. Take your opportunities as they arise!

Full instructions on when you should undertake each of the activities is provided on the course website. However, carrying out the activities at the recommended time may not always be possible for a variety of reasons, including extraordinarily bad weather, severe 'light pollution' (from ground-level lighting), your inability to be out at night, and so on. Check the 'Activities' section of the course website for details of what you can do in this case.

Learning outcomes

After studying this booklet and carrying out the observational activities, you should be able to:

- Use the celestial coordinate system.
- Describe the effect on star positions of the daily and annual motions of the Earth.
- Outline how the Sun, Moon and planets move against the stellar background, and understand, broadly, the cause of these motions.
- Use a planisphere to find celestial objects in the sky.

- Plan and carry out basic observational activities.
- Manipulate and display numerical data and their uncertainties in basic ways.
- Write a clear, concise account for an observational activity.

1 The sky: the view from the Earth's surface

1.1 Introduction

How do we measure the positions with respect to the Earth of celestial bodies, such as the stars? How do their positions change during the day and during the year? For instance, if you go out at, say, 10 pm on a February evening, how does the clear night sky differ from that at 11 pm, or from that at 10 pm a week or so later? How do the Sun, the Moon and the planets move against the stellar background? These fascinating questions are important in relation to the activity work (and of course the whole of observational astronomy), and you should be able to answer them after studying this section. However, in the rest of the course they are *not* the sorts of question that will much concern us: this is *not* a course in positional astronomy!

1.2 Mapping the sky

1.2.1 Celestial coordinates

To specify the position of a celestial body, we would like to have a coordinate system that is fixed with respect to the distant stars, just as on Earth we have a latitude and longitude coordinate system that is fixed with respect to the Earth's surface. Indeed, this terrestrial system is the basis of a celestial system that is a natural choice for Earth-based observers.

The terrestrial coordinate system is shown in Figure 1.1. The position of any point O on the Earth's surface is specified by two angles, the latitude *lat* and the longitude *long*. Anywhere on the line l_O has the same latitude as O – this is a line of latitude – and anywhere on the line L_O has the same longitude as O – this is a line of longitude. Longitudes are measured from a zero of longitude that has to be chosen. For historical reasons the zero is the line of longitude that passes through a particular telescope at the Royal Observatory, Greenwich, London. Longitudes extend from 0 degrees of arc (deg, or °) to 180° east of Greenwich, and from 0° to 180° west of Greenwich. The zero of latitude is the *Equator*. This is the line on the Earth's surface midway between the North and South Poles. These poles are where the Earth's rotation axis meets the Earth's surface. Latitudes extend from 0° to 90° north of the Equator at the North Pole, and from 0° to 90° south of the Equator at the South Pole.

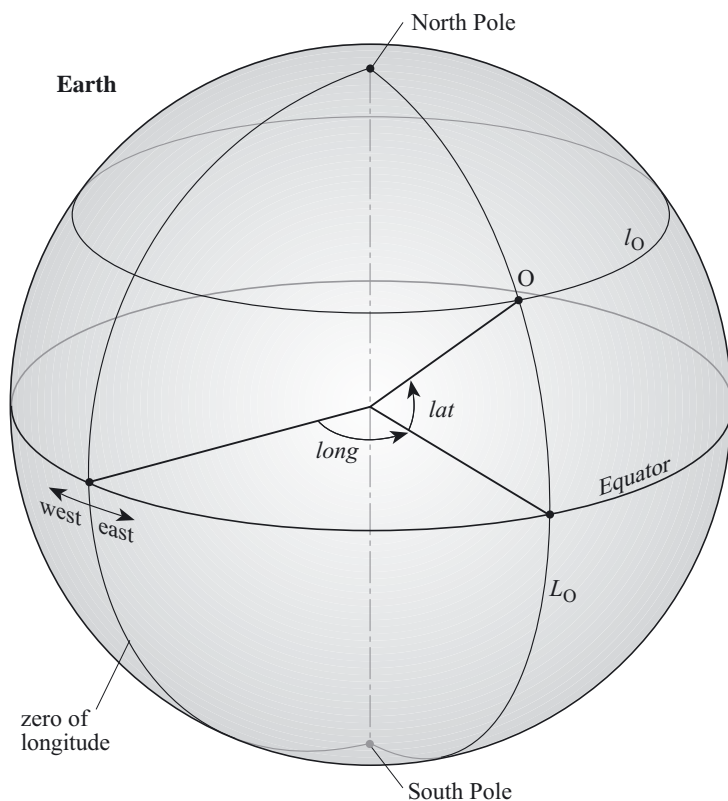


Figure 1.1 Terrestrial latitude and longitude.

The degree of arc can be subdivided into 60 minutes of arc (arcmin, or ') and the minute of arc can be subdivided into 60 seconds of arc (arcsec, or ").

To obtain a useful system of celestial coordinates, imagine the Earth to be surrounded by a sphere centred on the Earth's centre, as in Figure 1.2. This is called the **celestial sphere**. The line from the centre of the Earth through the North Pole intersects the celestial sphere at a point called the **north celestial pole**. The **south celestial pole** is defined in an analogous way. The projection of the Earth's Equator from the centre of the Earth on to the celestial sphere is called the **celestial equator**.

The Earth's rotation axis is very nearly fixed with respect to the distant stars. Certainly, on a human timescale, the north and south celestial poles and the celestial equator can be regarded as very nearly fixed: until further notice we shall regard them as fixed. We thus have the basis of a useful coordinate system, the *celestial coordinate system*, used by astronomers and by navigators.

Suppose that there is a celestial body in the direction shown in Figure 1.2. Its celestial coordinates are the two angles *dec* and *RA* – celestial latitude and longitude, respectively.

Celestial latitude is called **declination** (often abbreviated to 'dec' as in Figure 1.2) and, like terrestrial latitude, it extends from 0° at the celestial equator to 90° N at the north celestial pole, to 90° S at the south celestial pole, though the usual convention with *celestial* latitude is to write northern latitudes as positive, and southern latitudes as negative.

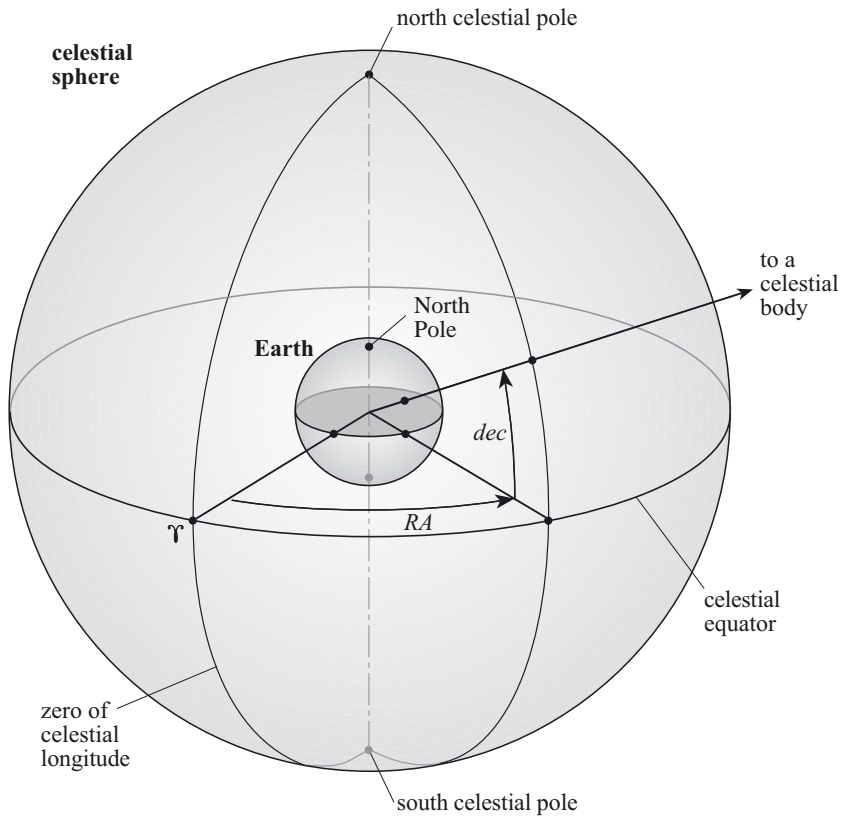


Figure 1.2 The celestial sphere.

Celestial longitude is called **right ascension** – *RA* in Figure 1.2. Note that right ascension is measured only eastwards from the zero of celestial longitude, and thus, in terms of degrees, runs from 0° to 360° . This is *one* difference from terrestrial longitude, which by convention, is measured from 0° to 180° east and from 0° to 180° west. There are two more differences. First, the zero of celestial longitude is *not* the projection onto the celestial sphere of the terrestrial zero of longitude.

- Why would such a projection not be useful?
- Such a projected longitude would sweep across the stars as the Earth rotates, and so the celestial longitude of every celestial body would continuously change.

Therefore, the zero of celestial longitude is specified by a particular point on the celestial equator that is fixed with respect to the distant stars. It follows that the *RA* of a celestial body is also fixed. For historical reasons the chosen point is called the **First Point of Aries**, which we shall denote by the symbol γ . (The astrological symbol for the constellation Aries.)

The second difference is that right ascension is not usually measured in degrees, but in hours! Right ascensions range from 0 hours ($+0^\circ$ longitude) to 24 hours ($+360^\circ$ longitude), which is back at zero. This convention arises from the rotation of the Earth, which rotates once a day at the centre of the celestial sphere (this will be discussed further in Section 1.3.1). The abbreviation for hours is ‘h’, and the usual subdivisions into minutes (min) and seconds (s) apply.

Strictly speaking, celestial coordinates are defined with respect to the Earth’s centre. However, we can make the celestial sphere so much larger than the Earth that, for practical purposes, from any point on the Earth’s surface the celestial sphere looks the same, and the celestial coordinates of distant celestial bodies have values practically independent of the position of the point on the Earth’s

surface. Such a celestial sphere is shown in Figure 1.3, where the Earth is so much smaller that it is shown as a point.

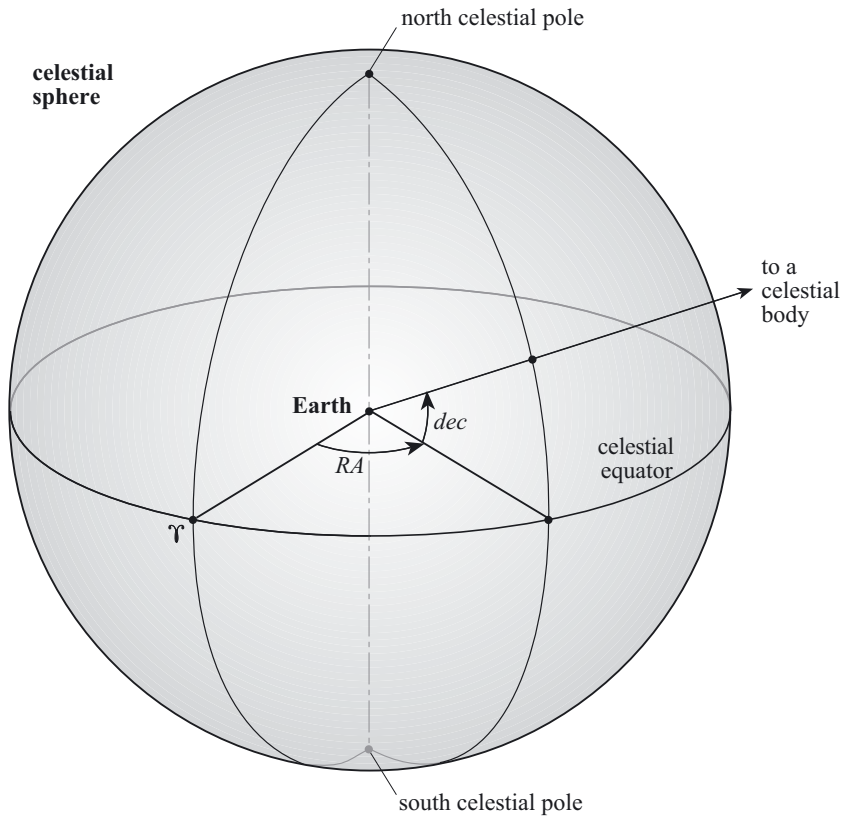


Figure 1.3 A larger celestial sphere.

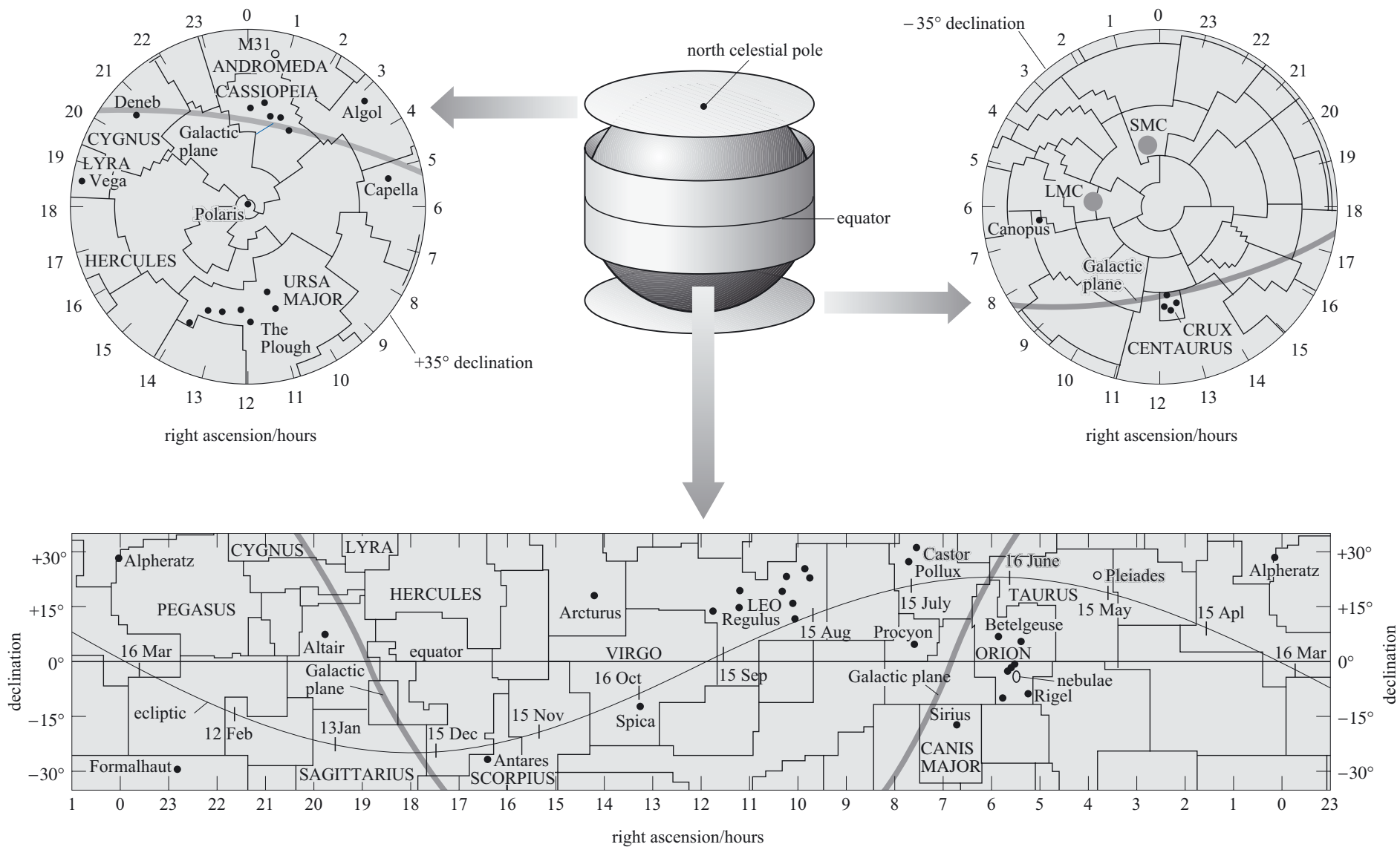
1.2.2 A map of the sky

A sphere is not a very useful form of map for the printed page. Figure 1.4 shows one way of projecting the celestial sphere on to a plane. We end up with a flattened view, looking outwards.

The entire sky (flattened or not) is divided up into 88 irregularly shaped regions, leaving no gaps (Figure 1.4). Each region is called a **constellation**, and all of them have names, though in Figure 1.4 only a few are shown. These regions of sky are based around patterns of stars (also known as constellations), some of which are easily recognizable: here we have shown just the more prominent stars.

Any body in the sky will have celestial coordinates that lie in a particular constellation, and the way to express this is to say that object X lies *in* Orion. Indeed, this provides us with a basis for labelling the brighter stars. This is done by using the letters of the Greek alphabet (α , β , γ , δ , and so on), followed by the constellation name, which is usually reduced to a standard three-letter abbreviation. Thus, in Orion we have α Orionis, β Orionis, etc. (the modified constellation name is the Latin genitive), which are abbreviated to α Ori, β Ori, etc. To include more stars, numbers are used instead of Greek letters. The brightest stars have individual names: thus α Ori is Betelgeuse ('betel-jers').

Figure 1.4 (*opposite*) A map of the sky, showing the constellation boundaries and some stars. (The names of the constellations are given in capital letters.) The other features will be discussed either in this booklet or elsewhere in the course.



A full list of the constellations and their equivalent English names is provided in Appendix A2 of *An Introduction to the Sun and Stars*.

In order to include faint stars and non-stellar objects the constellation-based system is abandoned and various catalogues are used. We shall not go into details here, though you will come across a number of particular examples in this course, notably the Messier Catalogue and the New General Catalogue. These are both used for non-stellar objects and star clusters. The Messier Catalogue was prepared originally by the French astronomer Charles Messier (1730–1817) and today consists of 110 bright objects of assorted types, labelled M1 to M110. The New General Catalogue is much larger, embracing 7840 objects, including all those in the Messier Catalogue. It was published in 1888 by the Danish astronomer John Louis Emil Dreyer (1852–1926), who spent much of his working life in Ireland. Entries in his catalogue take the form ‘NGC’, followed by a number.

Some objects do not have constellation-based names because their positions are not fixed and their celestial coordinates therefore move from one constellation to another. (In principle, all celestial bodies move with respect to each other and the positions of stars on the celestial sphere do change, but these changes are very small – see Section 3.2.1 of *An Introduction to the Sun and Stars*.) Notable amongst such bodies are the Sun, the Moon, and the planets, none of which are shown in Figure 1.4 for this very reason, though we have shown the annual path of the Sun – this is the line labelled ‘ecliptic’. We shall return to the motions of these bodies in Sections 1.3.2 and 1.3.3.

Before we leave Figure 1.4, note the star Polaris. With a declination of just over $+89^\circ$ its direction is close to the north celestial pole. Thus, it is often called the *Pole star*. The southern hemisphere is not as fortunately endowed.

1.2.3 The instantaneous view

Let’s consider now the view of the sky that we get *at a particular instant* from a particular point on the Earth’s surface, such as from the point O in Figure 1.5. The vertical direction at O is from the centre of the Earth upwards through O, and it is perpendicular to the horizontal plane at O. In this plane we have marked the north, east, south and west directions.

- How much of the sky can an observer at O see?
- An observer at O can see only the half of the sky that lies *above* the horizontal plane.

(Video sequence ‘Preparing for observing’ includes material on the celestial sphere; it is best to watch it when you have studied this file.)

The horizontal plane at O can be expanded to meet a celestial sphere much larger than the Earth, as in Figure 1.6. The plane intersects the sphere at the observer’s horizon in the stars, dividing the sphere into the visible and invisible hemispheres. The vertical direction at O intersects the celestial sphere at a point called the **zenith**; this is the point overhead at O. The *north point* at O is where the north direction in the horizontal plane at O (Figure 1.5) intersects the celestial sphere, and likewise for the east, south and west points. The **meridian** at O is the arc that connects the north point, the zenith, the south point, and the celestial poles: only the visible half is shown in Figure 1.6.

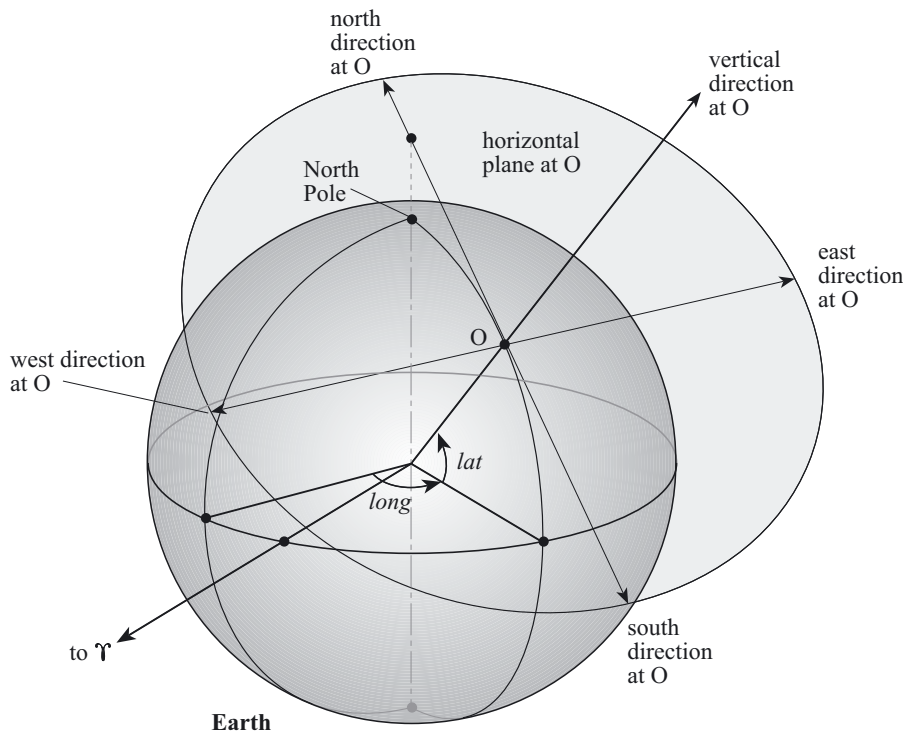


Figure 1.5 The horizontal plane at a point O on the Earth's surface. The three straight lines through O intersect each other at 90° .

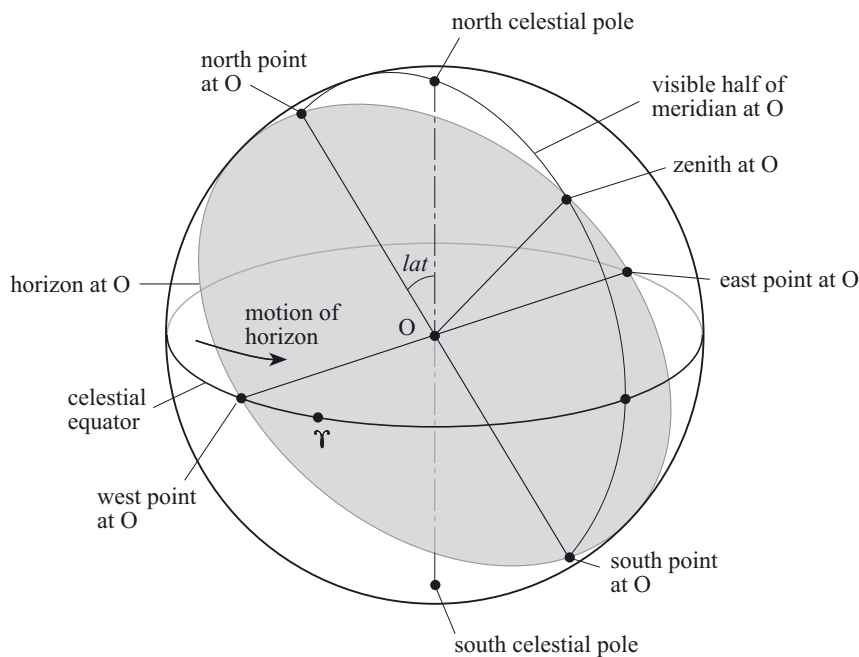


Figure 1.6 The horizontal plane at the point O on the Earth's surface (Figure 1.5), extended to meet a large celestial sphere.

The meridian is an example of a **great circle**. This is any line on a sphere that is the intersection between the sphere and a plane passing through its centre. The celestial equator is another great circle. When we measure angles between two points on the celestial sphere we do so along the great circle that connects them. One example is along the meridian itself: in Figure 1.6 we have labelled the angle between the north point and the north celestial pole. In fact, we have labelled it as *lat*, suggesting that it is equal to the latitude of O, and Figure 1.7 (*overleaf*) shows that indeed this is the case.

Finally, we need to define the **altitude** of a celestial body. This is the angle *alt* in Figure 1.8: it is the angle between the horizontal plane and the direction to the body, measured along the great circle that passes through the zenith and the point on the celestial sphere in the direction to the body.

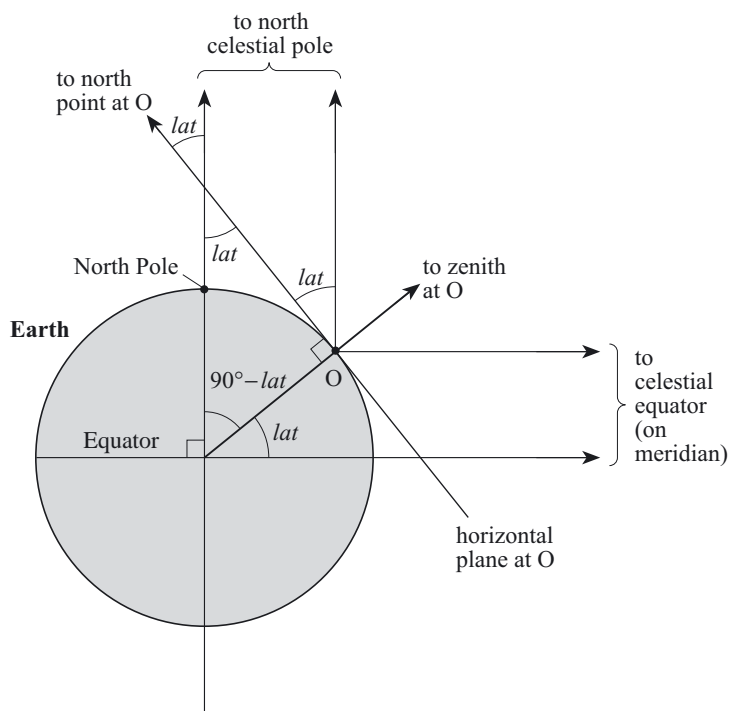


Figure 1.7 The angle at O between the north point and the north celestial pole is the latitude *lat* of O.

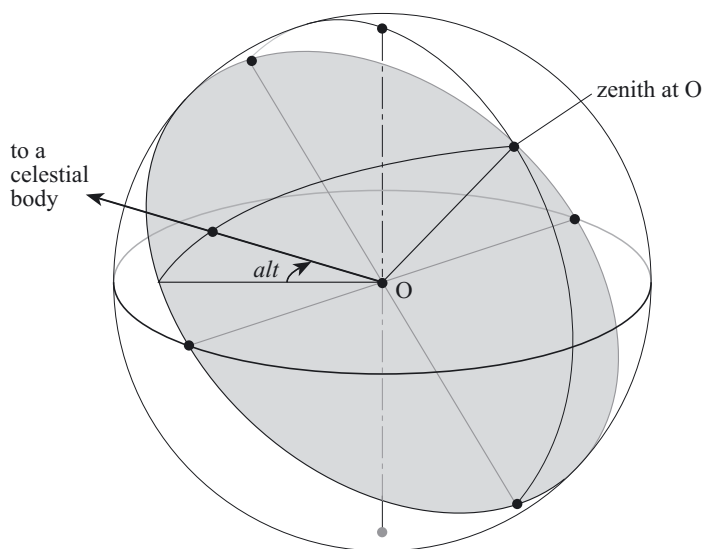


Figure 1.8 The altitude *alt* of a body.

1.3 A moving panorama

1.3.1 The effect of the Earth's motions

The visible hemisphere in Figure 1.6 for an observer at O on the Earth's surface is *not* fixed on the celestial sphere. This is because the Earth rotates on its axis once every day, anticlockwise as viewed from above the north pole – this direction of rotation is called **prograde** rotation, as opposed to **retrograde** rotation. The axis

of rotation is along the line joining the north and south celestial poles. Thus, the north point makes a circle around the north celestial pole once a day, with celestial bodies rising above the horizon in the east, and setting below the horizon in the west (see Figure 1.9). We shall return to this motion in Section 1.3.4.

The Earth not only rotates on its axis, but also orbits the Sun, taking a year to return to the same position with respect to the distant stars, as seen from the Sun. It revolves about the Sun in an orbit that, for present purposes, we can approximate as a circle with the Sun at the centre, and with the Earth moving at a uniform speed around the circle. The radius of the circle is 1.50×10^8 km.

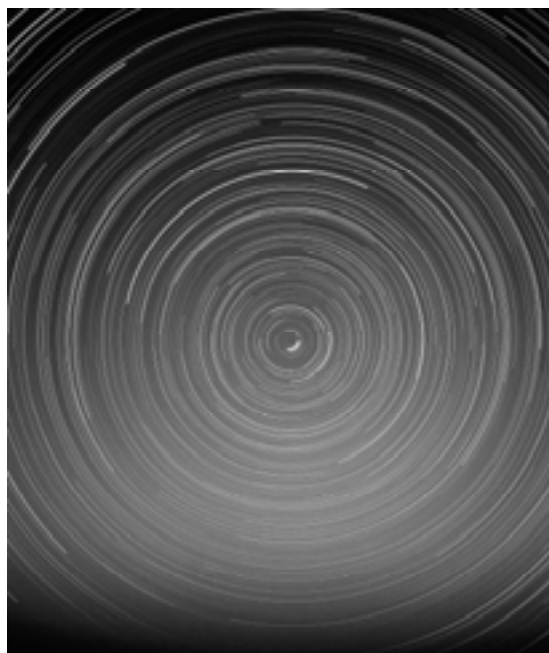


Figure 1.9 A long exposure of the sky showing the apparent motion of the stars as the Earth rotates. (David Parker/Science Photo Library)

The plane of the Earth's orbit is called the **ecliptic plane**. The Earth's axis of rotation is *not* perpendicular to this plane, but is inclined to the perpendicular at an angle of $23^\circ 27'$ as Figure 1.10 (*overleaf*) shows. Note that in this figure the non-circular shape of the Earth's orbit arises from the oblique viewpoint: it appears much more circular when we view it face-on, as the figure on the left shows. Note also that the dots representing the Sun and the Earth are not to scale – they are far too large! Most important of all, note that the direction of the Earth's axis remains fixed with respect to the distant stars, and *not* with respect to the Sun. At *A* the northern hemisphere is maximally tilted towards the Sun. This is called the *June solstice*, and happens on or near 21 June each year. The Earth moves anticlockwise around the Sun, as viewed from above the northern side of the ecliptic plane – prograde motion again. Thus, a quarter of an orbit later we reach *B* around 21 September, then *C* around 21 December (the *December solstice*), and then *D* around 21 March.

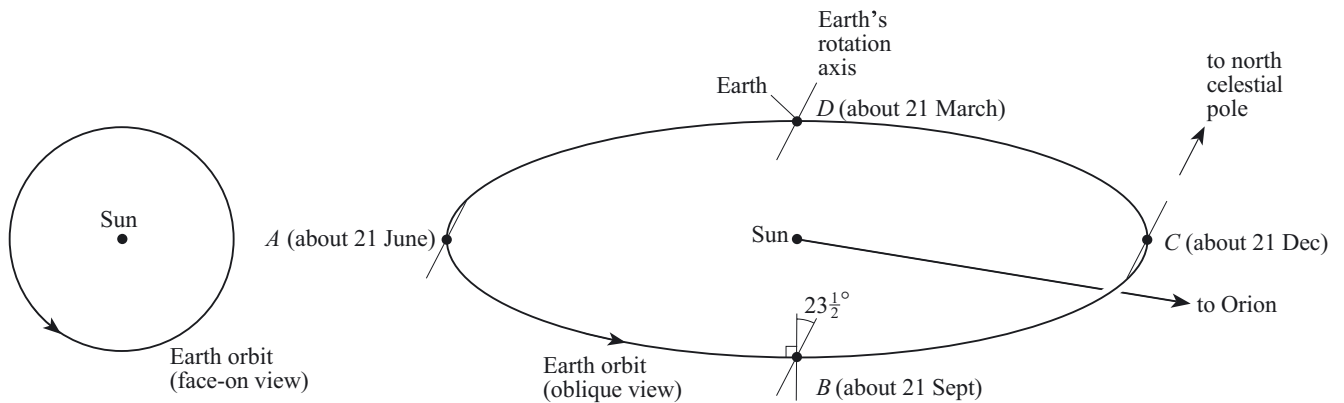


Figure 1.10 An oblique view of the Earth's orbit around the Sun, showing the Earth's rotation axis. The figure on the left shows that, face-on, the Earth's orbit is far more circular.

Figure 1.10 demonstrates that certain celestial objects are visible from the Earth at only certain times of the year, through the example of the constellation Orion. This lies in the direction shown. Therefore, around May and June each year, as seen from the Earth, Orion lies in about the same direction as the Sun, and so will not be visible – the sky will be too bright. By contrast, around November and December it lies in roughly the opposite direction to the Sun, and so will be visible for most of the night. During the other months it will be visible for less of the night. A different case is that of Polaris. The proximity of its direction to the north celestial pole means that in the northern hemisphere it never sets, so it is visible whenever it is dark.

■ What is the visibility of Polaris in the southern hemisphere?

□ It never rises, so it is never visible.

To examine further the changing relationship between the Sun and stars, let's examine the Earth at position 1 in Figure 1.11, where the direction to the Sun is on the observer's meridian – this defines local *noon*. Also, suppose that a star lies in the direction of this meridian. (There needn't be a real star, any point fixed on the celestial sphere will do.) As the Earth moves around its orbit it also rotates, and at position 2 it has rotated just once with respect to the distant stars, and so the star again lies in the direction of the meridian. This defines the passage of one **sidereal day** ('sidereal' means 'star related'). However, the Sun is not yet again in the direction of the meridian. The Earth has to rotate further (and it also moves further around its orbit) to achieve this configuration, as at position 3. The time elapsed between positions 1 and 3 is one **solar day**, and it is clearly longer than the sidereal day, though by only a few minutes (note that Figure 1.11 is not drawn to scale).

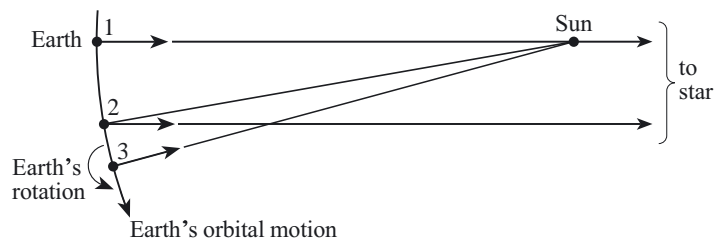


Figure 1.11 The difference between the sidereal day and the solar day: the straight black arrows denote the direction of the observer's meridian (not to scale).

The familiar day of civil time is not *quite* the same as the solar day. This is because during the year there are small variations in the intervals between the Sun's crossing of an observer's meridian, and hence in the length of the solar day. These variations arise mainly from the tilt of the Earth's rotation axis and from the Earth's orbit being slightly different from circular; we will not go into details here. By contrast, the **mean solar day** is fixed in duration. If solar time and mean solar time coincide at some instant they will coincide again a year later, but in between differences develop, sometimes solar time being ahead of mean solar time and sometimes behind. The civil day is equal in length to the mean solar day.

If we use the terms hours (h), minutes (min) and seconds (s) to denote subdivisions of the 24 h mean solar day (or civil day) then the sidereal day is 23 h 56 min 4 s long, i.e. 3 min 56 s shorter. This difference means that, according to mean solar time, the distant stars cross the observer's meridian 3 min 56 s earlier every day, which amounts to 27 min 32 s earlier every week. Thus, the stellar sky at say 22 h 0 min 0 s (mean solar time) on a certain day, looks the same as the stellar sky at 21 h 32 min 28 s seven days later. The stellar sky thus progresses westwards with respect to the Sun, taking one year for the differential cycle to be completed.

This extra rotation per year of the stellar sky means that there is one more sidereal day in the year than there are mean solar days. Thus, with 365.26 mean solar days per year, there are 366.26 sidereal days per year.

Mean solar time is a local time, in that observers at different longitudes will observe the Sun in the direction of their meridians at different times. For civil purposes this is very inconvenient and so the world is divided up into time zones, where *civil time* is the same within each time zone. Mean solar time will vary with longitude across the zone, typically by one hour from the west to the east extremities of the zone. In most countries there is also *daylight saving time*, in which civil time is advanced by an hour in the spring and summer months: in the UK this is called British Summer Time.

1.3.2 The changing celestial coordinates of the Sun

Let's now add a celestial sphere to the Earth in Figure 1.10. We obtain Figure 1.12. Note that as the Earth orbits the Sun the celestial sphere remains fixed with respect to the distant stars, and this is indicated by the fixed orientation of the line joining the north and south celestial poles and by the fixed direction of Υ , which lies on the zero of right ascension. The positions on the celestial sphere of even the nearer stars barely change as the Earth orbits the Sun because the Earth's orbit is very small compared with their distance. However, the Sun's celestial coordinates change dramatically, and we shall now use Figure 1.12 to map these changes.

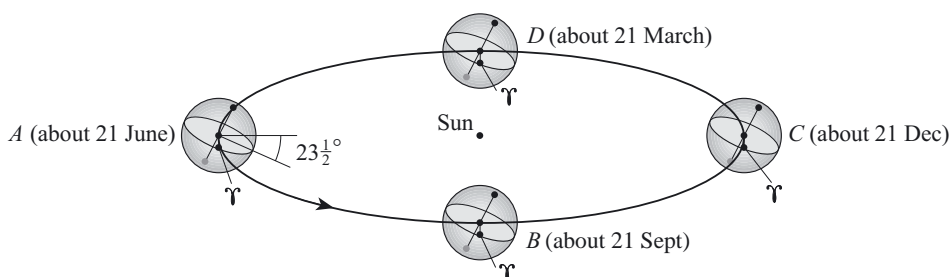


Figure 1.12 The changing celestial coordinates of the Sun.

When the Earth is at *A* the Sun has a right ascension 6 h and a declination $+23\frac{1}{2}^\circ$ (the June solstice). At *B* the values are 12 h, 0° . The zero declination at *B* means

that the direction to the Sun is on the celestial equator, the declination changing from north to south. At such a time there is close to 12 hours between sunrise and sunset all over the Earth, as Figure 1.13 shows. Such an event is loosely called an *equinox* (equal day and night) but strictly an equinox is the precise moment when the direction to the centre of the Sun is on the celestial equator. At *C* the Sun's celestial coordinates are 18 h, $-23\frac{1}{2}^\circ$ (the December solstice). At *D* we have the other equinox, the March equinox, with the Sun at 0 h, 0° . The complete trace of the Sun's celestial coordinates is shown in Figure 1.14, and is called the **ecliptic** (also shown in Figure 1.4). Note that this is a great circle on the celestial sphere, the intersection of the ecliptic plane with the celestial sphere.

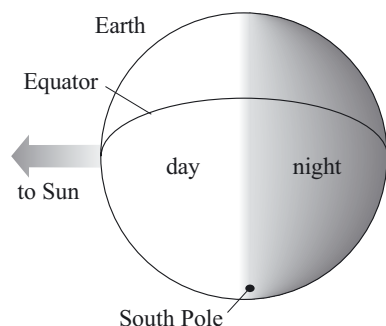


Figure 1.13 The Earth in position *B* in Figure 1.12, viewed from a point in its orbit just behind the Earth.

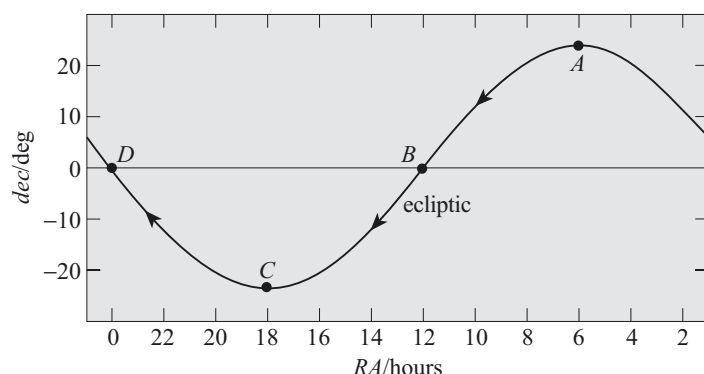


Figure 1.14 The changing celestial coordinates of the Sun. *A* is ~ 21 June, *B* ~ 21 September, *C* ~ 21 December, *D* ~ 21 March.

You have just seen that at the March equinox the right ascension of the Sun is zero, and so the Sun lies in the direction of Υ . *This is no coincidence*, for it is how the zero of right ascension is defined! Thus, the zero of celestial longitude is the line of celestial longitude that passes through the celestial equator at the point where the declination of the Sun is changing from south to north.

If the Earth's rotation axis *really* was fixed with respect to the distant stars then the direction to Υ would be similarly fixed. Unfortunately the axis is not quite fixed, so the celestial coordinate frame moves very slowly with respect to the stars.

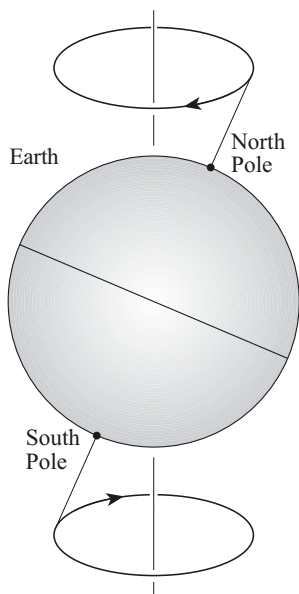


Figure 1.15 The precession of the Earth's rotation axis.

Although this effect is small it must be accounted for, since over long periods of time the positions of stars will drift further and further from their catalogued positions. The largest effect by far is the so-called **precession** of the Earth's rotation axis, shown in Figure 1.15, the Earth's rotation axis taking 25 800 years to complete one circuit. Thus, celestial coordinates go through a 25 800 year cycle. We shall consider this no further, except to note that *dates* are often added to celestial coordinates to specify the time at which they are correct.

1.3.3 The apparent motion of the Moon and planets

The Moon orbits the Earth, and is easily the Earth's nearest neighbour, in fact nearly 400 times nearer than the Sun. Figure 1.16 shows the lunar orbit (enlarged) in relation to the Earth's orbit on four occasions during the year. The plane of the lunar orbit makes only a small angle (around 5°) with respect to the ecliptic plane. Therefore, as the Moon orbits the Earth its celestial coordinates are never far from the ecliptic in Figure 1.14. Note that we have added no dates to Figure 1.16. This is because the orientation of the orbit of the Moon is not quite fixed with respect to the Earth's orbit.

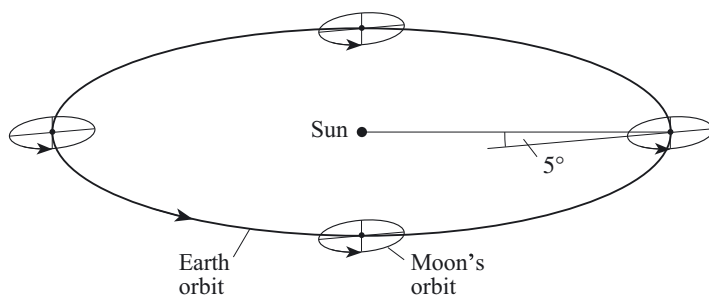


Figure 1.16 The Moon's orbit (enlarged): an oblique view.

Figure 1.17 (*overleaf*) shows the Moon in its orbit; the size of the Moon is *greatly* exaggerated, and the orbit has been approximated by a circle with the Earth at its centre. The Moon shines by reflecting the Sun's radiation, and so the lunar phases depend only on the angle between the Moon and the Sun, as seen from the Earth. Thus, when the Moon and Sun lie in roughly the same direction we have a new Moon – essentially invisible unless the Moon passes exactly between an observer and the Sun, when they observe a *solar eclipse*. A new Moon occurs at intervals,

on average, of 29.53 days. At the other extreme, when the Moon and Sun lie in roughly opposite directions, the Moon is full. When the angle between the Moon and the Sun is 90° the Moon is half full; these positions are marked first and third *quarters* in Figure 1.17.

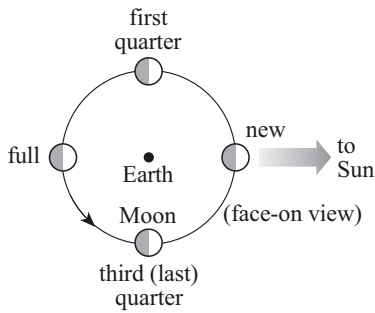


Figure 1.17 Lunar phases (not to scale).

- In what sense are these positions *quarters*?
- They are one quarter and three quarters of the time through the lunar cycle, starting at new Moon.

The Moon rotates on its axis in the same time that it takes to orbit the Earth, and in the same direction. This is called **synchronous rotation**. As a result, the Moon presents more or less the same face towards the Earth – the familiar ‘Man in the Moon’ pattern. However, largely because the Moon’s orbit around the Earth is not perfectly circular and also because its rotation axis is not quite perpendicular to the plane of its orbit, we do see rather more than half the Moon’s surface. The Moon’s surface, *as we see it*, appears to oscillate slightly in various ways around a mean position. The apparent oscillations are called **librations** and they allow us to see about 59% of the lunar surface from the Earth.

Beyond the Moon we come to the planets. These move in orbits around the Sun, in planes that, in most cases, make small angles i with respect to the ecliptic plane (Table 1.1). Therefore, the celestial coordinates of these planets stay close to the ecliptic. The details vary from planet to planet, and from year to year.

Table 1.1

Planet	i/deg	Planet	i/deg
Mercury	7.00	Saturn	2.49
Venus	3.39	Uranus	0.77
Mars	1.85	Neptune	1.77
Jupiter	1.30	Pluto	17.2

1.3.4 The planisphere

We are now in a position to consider in a bit more detail the effect of the Earth’s motions on an observer’s view of the sky. In particular, we want to establish which half of the celestial sphere is above an observer’s horizon at any particular date and time. A **planisphere** is a device that supplies this information, and an example is shown in Figure 1.18. However, you should also have your own planisphere to hand. Please examine it. For the given latitude (give or take a few degrees) the lower sheet displays all of the sky ever visible from that latitude. You can see that, around the edge of the lower sheet, the right ascension is given in hours and in degrees, and that along several of the radial lines the declination is

given. The lower sheet also carries a scale that shows various dates through the year – we shall come back to this shortly.

The upper sheet rotates on the lower sheet around a point that represents the north celestial pole (we shall assume that the observer has a northern latitude). This sheet has an aperture, the boundary of which represents the observer's horizon. Within the aperture is the hemisphere of sky on view at a particular date and time. To select a particular date and time, line up the desired local mean solar time on the upper sheet with the date on the lower sheet. Your civil time should be sufficiently close to local mean solar time except if daylight saving time is in force, when you should then subtract an hour from civil time.

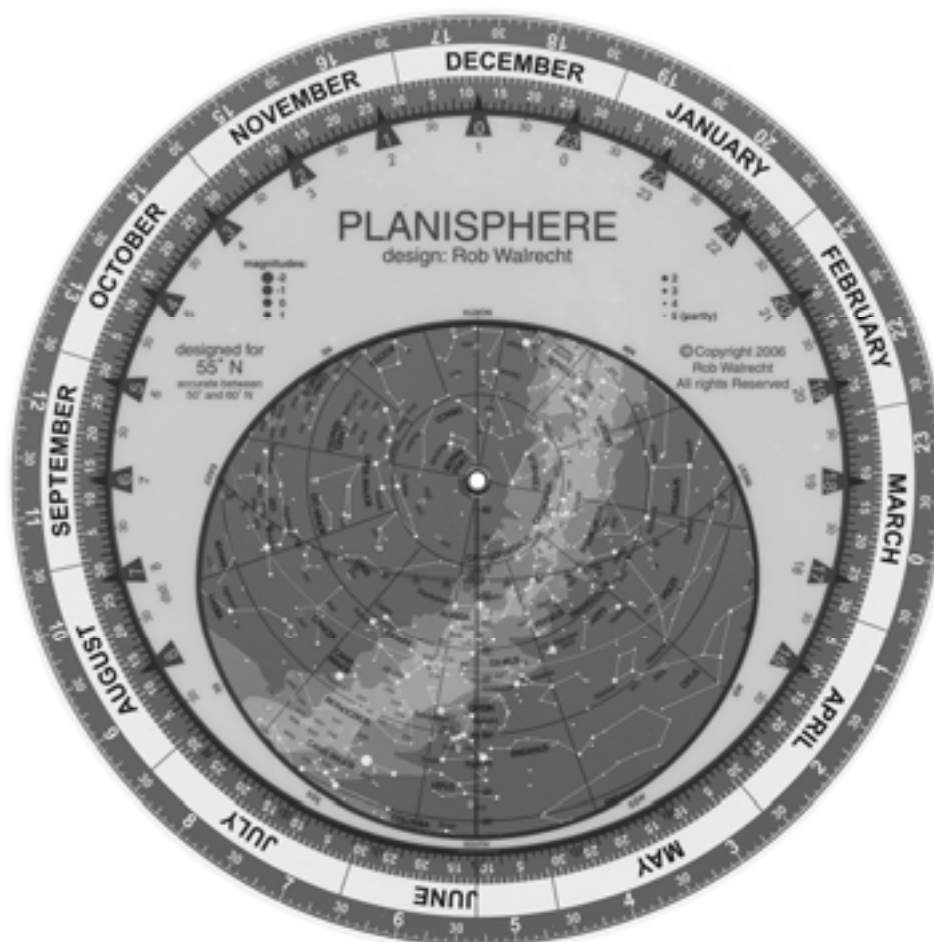


Figure 1.18 A planisphere.

In Figure 1.18 we have marked the visible half of the meridian, the zenith, the north celestial pole, and the north and south points. The planisphere itself marks the eastern and western horizons. (Note that, because we are representing a portion of a sphere on a plane, the planisphere has geometrical distortions.) Compared with terrestrial maps you can see that east and west are reversed. This is because the planisphere is to be held above your head, and you are to look up at it, with the meridian correctly orientated. That's all there is to using it!

You can also use your planisphere to simulate the effect of the Earth's rotation. Slowly rotate the upper sheet, in a clockwise direction, and note the stars rising in the east, reaching their highest altitude as they cross the meridian, and setting in the west. If you line up a particular time with a particular date, say 22 h (10 pm) on 14 February, and rotate the upper sheet clockwise until the same time lines up with 15 February, then you have simulated the passage of one mean solar day.

Note that, in such a case, the sky has shifted slightly westwards – this is because of the difference between the solar and sidereal days (due to the motion of the Earth about the Sun).

As you rotate the upper sheet you can also see the effect of declination on the apparent motion of a celestial body across the sky. At a sufficiently large negative (southerly) declination a celestial body never rises, but remains always below the horizon. Then, as we select bodies with more and more positive (northerly) declinations, there comes a point at which a body just touches the horizon at the south point. As the declination becomes yet more positive the rising and setting points move further away from the south point, and the time between rising and setting increases. The maximum altitude of the body, which occurs when it is on the meridian, also increases.

- What is the declination of a body that spends 12 hours above the horizon?
- Using the planisphere we see that such a body has zero declination – it lies on the celestial equator.

Such a body rises at the east point and sets at the west point – see Figure 1.6.

We ultimately reach a declination above which a body is *always* above the horizon. Such a body is called a *circumpolar* body. The higher the latitude the greater the fraction of the sky that is circumpolar.

We hope that you enjoy using your planisphere to explore the sky. But first you should use it to tackle Question 1.4.

1.4 Summary of Section 1 and questions

- Celestial coordinates are based on the celestial sphere, the poles and the equator of which are projections of the poles and the Equator of the Earth.
- Celestial latitude is called declination, and is measured in degrees north and south of the celestial equator. Often, degrees north are denoted by positive values and degrees south by negative values.
- Celestial longitude is called right ascension, and is measured eastwards in hours, where a 24 hour change is equivalent to a 360° change in celestial longitude. The zero of celestial longitude is marked by the First Point of Aries, Υ . The north and south celestial poles, the celestial equator, and Υ , are all very nearly fixed with respect to the distant stars.
- At any instant, an observer on the Earth's surface will see only one half of the celestial sphere.
- Civil time is based on the Sun, with the familiar day more accurately called the mean solar day. Owing to the Earth's orbital motion around the Sun, for any given point on the Earth's surface the appearance of the stellar sky on mean solar day $n + 1$ will be the same as it was about 4 minutes *later* on mean solar day n .
- Owing to the Earth's orbital motion, and the inclination of its rotation axis with respect to its orbital plane (the ecliptic plane) the Sun's celestial coordinates change. They trace out a path on the celestial sphere called the ecliptic, which is the intersection of the ecliptic plane with the celestial sphere.
- The celestial coordinates of the Moon and the planets also change, and because the orbital planes of most of these bodies make small angles with respect to the ecliptic plane, the celestial coordinates of most of them trace out paths on the celestial sphere close to the ecliptic.

- A planisphere is a useful tool for displaying the celestial hemisphere visible to an observer at a given latitude, at any time of the day and on any date in the year.
- As the Earth rotates, the visible hemisphere changes, but (for an observer away from the Earth's Equator) there is a portion of sky that never sets, and another portion that never rises.

Question 1.1

The celestial coordinates of the star β Trianguli are 2 h 9.2 min, $+34^\circ 57'$, and those of the star θ Centauri are 14 h 6.4 min, $-36^\circ 20'$. Roughly speaking, how far apart are the directions of the two stars in the sky?

Question 1.2

- (a) What is the altitude of
- (i) the north celestial pole (for an observer in the northern hemisphere) and
 - (ii) the zenith?
- (b) Suppose that, from some point on the Earth's surface, the Sun, at some particular moment, has an altitude of $64^\circ 21'$. How many degrees and minutes of arc is it from the zenith?

Question 1.3

For observers at latitudes 90° N, 50° N and 0° , describe, with the aid of sketches similar to Figure 1.7, where the celestial equator lies in the sky in each case.

Question 1.4

Use your planisphere to tackle this question. *Note:* a star on the horizon should be positioned with its centre just covered by the red horizon line.

- (a) (i) On 18 February, at what mean solar times does the star Rigel (in Orion) rise, and then cross the meridian? At what time does it set (on 19 February)?
- (ii) Why would Orion not be visible on 18 February for the whole of the time between its rising and setting, given clear skies?
- (iii) At what mean solar time does Rigel rise on 5 March?
- (b) On 18 February, at 02 h, the Plough (Figure 1.4) straddles the observer's meridian almost overhead (for latitudes from 50° N to 60° N). Where does the Plough appear 12 hours later?
- (c) Obtain the number of hours between the rising and setting times of the following stars: (i) Sirius ($6\text{ h }45\text{ m}$, $-16^\circ 43'$); (ii) Aldebaran ($4\text{ h }36\text{ m}$, $+16^\circ 31'$); (iii) The Sun, around 21 June.

For further training in using your planisphere, please see the 'Planisphere' section on the course website.

2 Planning and carrying out observational activities

2.1 Introduction

The success of observations, as with all practical scientific work, is critically dependent on careful planning and execution. Clear skies are not to be wasted in the UK! It is thus important to think through what needs to be done, to list what needs to be taken to the site, and to have a ‘dress rehearsal’ with *all* necessary documentation and equipment, in the comfort and convenience of indoors in the light. We discuss here the selection of a suitable observing site and the equipment you will need.

2.2 Choosing a site

A vital part of planning is to select an observational site in accord with the following points.

- *Do* ensure that the relevant part of the sky will be visible. Even when the sky is not clear this can be established by means of the planisphere, provided that for your site you know where north is. You can establish the northerly direction well enough for S282 activity work by means of a magnetic compass: in the UK the direction to the Earth’s north magnetic pole is less than 10° from the direction to the north point, magnetic north being to the *west* of the north point.
- *Do* avoid ‘light pollution’ – bright skies caused by ground light reflecting off solid and liquid particles in the atmosphere. Light pollution is reduced if the sky is very clear, and if the object in the sky is nearest its highest altitude, i.e. near your meridian. And, of course, it is also reduced if the level of ground light is reduced. Thus, avoid being near a bright light and, if possible, avoid being in general urban lighting. Alas, most of us will have to put up with urban lighting, but it’s surprising how much can be done provided that we don’t stand underneath a street lamp or in a floodlit playing field.
- *Don’t* pick a site that is difficult to get to. It is important to be able to take advantage of temporarily clear skies. In any case, difficult access would be a strong disincentive to making observations.
- *Do* ensure that objects, such as lamp-posts or edges of building, needed for directional reference are clearly visible (see the activity instructions for details).
- *Do* bear in mind personal security.

If you have a garden or even a suitably positioned open window then this can be hard to beat as an observational site for the S282 observational activity work.

2.3 Equipment

2.3.1 What to take

Let’s suppose that the weather is OK. What’s next? First, ensure that all of the following items are ready to go:

- The relevant observational activity instructions
- A torch (flashlight), preferably with a means of dimming it so that it doesn’t destroy your dark adaptation (see below). One way to dim a torch is to colour the bulb red with a felt tip pen or red film (sweet wrappers are good for this). Covering the front glass with a piece of card pierced by a small hole is another good way to dim your torch.

- A *bound* activity notebook (see below) plus something to write with
- A waterproof bag for the documentation
- The planisphere and, if available, binoculars (see below), binocular support.

Also, *do* wear warm clothing, not forgetting your feet, hands, and head.

2.3.2 Some advice on binoculars

Note: it is *not* necessary to obtain binoculars to complete the S282 activities.

Never look at the Sun through binoculars, or a telescope – you would certainly damage your eyes, and perhaps even blind yourself. Even with the unaided eye, don't stare at the Sun.

The two main properties of binoculars that concern us are, fortunately, almost invariably quoted by the manufacturer. These are the **aperture**, which is the diameter D of the big lenses in the front and the **angular magnification** m (the factor by which the angular size of the object is increased when you look through the binoculars). Almost all manufacturers describe binoculars as ' $m \times D$ ' with D in millimetres. For example, 7×50 binoculars have $m = 7$ and $D = 50$ mm. What values of m and D should you go for?

The value of D determines how much light from an object is collected: the larger the value, the greater the **light-gathering power**. For objects like stars, with no *apparent* physical extent at even the highest magnifications, the greater the light-gathering power the fainter the faintest star that can be seen through the binoculars. For objects with obvious physical extent (extended objects), such as the Moon, D determines how much detail there is in the image the objective lenses form. These images are scrutinized by us via the binocular eyepieces, so that we can see the detail available.

Clearly the larger the value of D the better. However, the cost of binoculars soars as D increases, particularly above 50 mm. Also, the binoculars get increasingly bulky and heavy. On the other hand, with D less than about 20 mm the light-gathering power is so modest that cost effectiveness is poor.

You might also think that the larger the value of m , the better. This is *certainly not* the case. Ultimately, there is an upper limit to m imposed by the amount of detail in the image produced by the objective lens – there's no point in using eyepieces that increase m beyond the value necessary to render this detail apparent to our eyes. But before we reach this limit two practical problems arise. First, at larger m , the more difficult it becomes to hold the binoculars steady enough to see the detail the magnification provides in the image. Also, if m is too high then, for extended objects, the brightness of the image on your eye's retina will be low, and we have a large but dim image. On the other hand, if m is too low then we end up with very small images of extended objects.

There is thus a compromise value for m , and this depends on the value of D . A rough rule of thumb is that m should be around $(D/\text{mm})/6$. Thus, for $D = 50$ mm we want $m \sim 8$, say in the range 7 to 12, and if $D = 20$ mm we want $m \sim 3$. In fact, small D binoculars usually have m greater than given by our rule of thumb. This is because they are intended for daytime use, where image brightness is not usually much of a problem.

As well as m and D , binocular manufacturers often also give the **field of view**. This is the angle across the sky of the view seen through the binoculars, and will be several degrees. On the whole, the higher m , the smaller the field of view.

For given values of m and D a considerable price range will probably be encountered, reflecting the overall optical and mechanical quality. Fortunately, for the S282 observational activity work the bottom end of the price range will do! Commonly found inexpensive types are 6×20 , 8×30 and 7×50 . While the first two can be extremely compact and lightweight the 7×50 is manageable and the best choice for astronomical use.

Let's now turn briefly to how to support the binoculars. If binoculars are hand-held, then it can be difficult to hold them steady enough, particularly for observing faint objects or fine detail. However, if you hold the binoculars towards the objective lens end, rather than towards the eyepiece end, then greater image steadiness should be achieved. You can also try leaning your body against a wall. For objects not too near the zenith, a wall or step ladder can provide valuable support for the binoculars. For objects near the zenith, an additional problem with unsupported binoculars is the fatigue that quickly sets in. The solution here is to have a reclining chair of some sort, or to lie on a blanket on the ground. Any support requirements that are more exacting are discussed in the relevant activity instructions.

Finally, a word about *telescopes*. On the whole these are *not* as suitable as binoculars for first experiences of observing the sky. This is mainly because

- two eyes really are better than one, for psychophysical reasons
- most telescope-eyepiece systems have high magnifications with $m > 25$, and so will *have* to be mounted on a rigid stand
- the field of view will be small at such large magnifications.

However, if you already have a telescope *with a rigid stand*, then it *will* be possible to use it for the S282 observational activities provided that you stick to low magnifications.

2.4 Getting started

When it comes to making observations the weather can be a source of frustration, so even though the S282 observational activity work requires only a few hours of clear skies you should take every reasonable opportunity as it arises. Note that satisfactory observations can be made in slight haze and in broken cloud.

When you get on to your site allow about five minutes for your eyes to begin to get dark-adapted, particularly if it is a dark site. Then, make the observations. In picking out faint stars you could try *averted vision*. If you direct your gaze *slightly* to one side of a faint star, the previously invisible star might become visible!

Do take care to make a neat record as you proceed, and make this record in a *bound* notebook – loose pages have a habit of blowing away, or getting lost. In any case, each page of the notebook should carry the date, the time, and the site location. Make a *neat, full* record of your own observations and measurements, of any difficulties or unexpected events encountered and of the degree of cloudiness, haziness and light pollution. If you obtain numerical data you should treat it as outlined in Section 3.

2.5 Summary of Section 2 and questions

- For successful observational activity work:
 - select a suitable site by visiting candidate sites
 - have a ‘dress rehearsal’ with all necessary documentation and equipment
 - keep an activity notebook, recording data and making notes as you proceed with the activity.
- For any activities in S282 that require binoculars, apertures D of 20–50 mm will do (though preferably greater than 30 mm) with angular magnification $m \sim (D/\text{mm})/6$. Take care to hold the binoculars steady, in a comfortable position. **DO NOT LOOK AT THE SUN THROUGH BINOCULARS** (or telescope), and do not stare at the Sun with the unaided eye.

Question 2.1

For first experiences of observing the night sky, you have to choose between 12×20 binoculars, and 7×30 . Explain which one is the more suitable.

3 Handling numerical data

The following two examples will serve to cover the points that we wish to make. No observational activity in S282 will require any more sophisticated numerical analysis than this. Indeed, most will require less.

3.1 Example 1: uncertainties in measurements

Let’s suppose that we have measured the declination of the Sun on some date in May, and obtained the value 19.5° . First, note that the units (degrees) have been attached to the quantity – this is something you must always do, and at the time of measurement.

Another thing you must always do is to attach an **uncertainty** to a measured value – an estimate of how different the value of the quantity could have been. With only *one* measurement of the declination the uncertainty would be our estimate of the accuracy of the measuring equipment, and the precision with which we could read the scale on it. Let’s suppose that the estimate of the uncertainty is 0.5° . This means that the true value of the declination probably lies between about 19.0° and 20.0° . We would then write the measured value as $19.5^\circ \pm 0.5^\circ$.

A different way of arriving at the uncertainty is to make the measurement more than once. Suppose that we measured the solar declination ten times and obtained the following values: 19.5° , 18.8° , 20.0° , 19.8° , 20.5° , 19.3° , 19.4° , 20.0° , 19.7° , 19.0° . The first step is to obtain the value to quote. This is the **mean value** – the sum of all the values divided by their number. In this case we get $196.0^\circ/10$, i.e. 19.6° . To obtain the uncertainty in this value we can calculate the **standard deviation** (a measure of the spread of the data) which is 0.5° . Alternatively, if you haven’t yet come across standard deviation you can adopt the following rough and ready approach: out of n measurements, we ignore the smallest $n/6$ and the largest $n/6$, and set the uncertainty equal to half the range of the remaining values. Applying this recipe to the above ten values, we ignore 18.8° , 19.0° , 20.0° , and 20.5° , leaving the range 19.3° to 20.0° . The uncertainty is then $(20.0^\circ - 19.3^\circ)/2$, i.e. 0.4° . We thus write $19.6^\circ \pm 0.4^\circ$.

Note that this second approach will not necessarily reveal any faults in the equipment, which could lead to a bias towards values that are either too high or too low. Such faults are an example of **systematic errors**, as opposed to the **random errors** revealed by repeated measurements. Often it is possible to arrange that systematic errors are negligible.

3.2 Example 2: uncertainties and graphs

Let's suppose that in order to measure the difference in length between the sidereal and mean solar days we have measured the civil time at which a certain star crossed our meridian on a series of dates. The fictitious but plausible data are shown in Table 3.1.

Table 3.1 Some (fictitious) data on meridian crossing times of the star OU Fic.

Date	Civil time of crossing	Uncertainty
20 February	21 h 14 min 24 s	± 2 min
27 February	20 h 46 min 53 s	± 2 min
2 March	20 h 34 min 08 s	± 2 min
3 March	20 h 29 min 47 s	± 2 min
13 March	19 h 52 min 11 s	± 2 min
14 March	19 h 47 min 33 s	± 2 min

This is the sort of table that should appear in your activity notebook. It is clearly laid out, and it gives the *units* in which each quantity was measured: remember that you must always attach the units to a quantity. Also given is a ± 2 min uncertainty in the civil times of crossing (there was no uncertainty in the dates!), arising from the limitations of the observational set-up. Thus, on 20 February for example, the true crossing time could have been at any time between about 21 h 12 min and 21 h 16 min.

It is clear from Table 3.1 that the crossings get earlier by about 4 minutes every civil day, i.e. every mean solar day. But is this drift steady, and what is the best value we can get from the data? To answer these questions we plot a graph – a useful way of exploring the relationship between two quantities. The two quantities here are the crossing times versus the number n of crossings since 20 February (with 28 days in February). Table 3.2 tabulates these data. Given the ± 2 min uncertainty in the crossing times, these times have been rounded to the nearest minute: you should always match the number of significant figures to the uncertainty.

Table 3.2 Number of crossings versus crossing time.

Number, n	Civil time of crossing	Time t after 19 h/min
0	21 h 14 min ± 2 min	134 ± 2
7	20 h 47 min ± 2 min	107 ± 2
10	20 h 34 min ± 2 min	94 ± 2
11	20 h 30 min ± 2 min	90 ± 2
21	19 h 52 min ± 2 min	52 ± 2
22	19 h 48 min ± 2 min	48 ± 2

Figure 3.1 shows a graph of the data in Table 3.2, where times are given as minutes t after 19 h. Note first that we have used graph paper – if you use a computer spreadsheet to construct graphs then you still need to include uncertainties such as error bars as detailed below. Second, note that the number n is along the horizontal axis. By convention the horizontal axis is always used for the variable that is more under the observer’s control than the variable on the vertical axis. Third, note that the axes are labelled, and that the units on the axes are shown by dividing the axis label by the units: the values can then be displayed as dimensionless numbers (n is already a dimensionless number). Fourth, note that we have used a convenient scaling on each axis, e.g. on the t -axis one small division represents 1 minute. Finally, note that the uncertainties are shown as lines on the data points, with a length corresponding to 2 minutes above and below the point. These lines are called **error bars**.

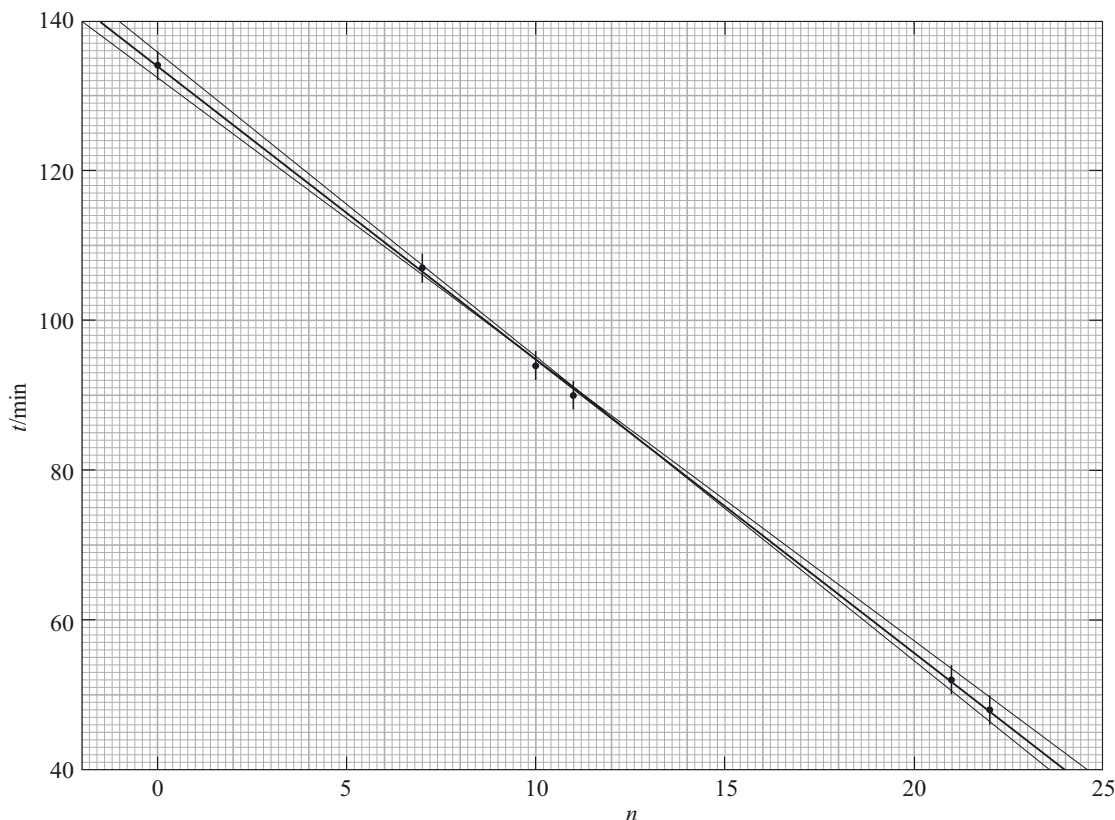


Figure 3.1 Fitting straight lines to data.

The first thing apparent from the graph is that we can draw the central straight line shown that passes within the error bar of every point (it would not have mattered if we had just missed one or two error bars). A straight line in Figure 3.1 corresponds to a steady change in crossing time with crossing number. Therefore, there is *no* evidence here for anything other than a steady change.

The central straight line is also a ‘**best fit**’ to the data. It has been obtained by ‘hand-and-eye’ estimation, which is good enough for the purposes of the S282 observational activity work, though there are more precise, numerical approaches. The gradient of the best-fit straight line, in effect, uses *all* of the observational data to provide us with a good estimate, from the data, of the difference in length between the sidereal and mean solar days. The gradient, using the values of t taken at $n = 0$ and 20, is given by

$$\frac{55.4 - 133.7 \text{ min}}{(20 - 0) \text{ crossings}}, \text{ i.e. } -3.92 \text{ min per crossing.}$$

Therefore, the sidereal day, from the data, is 3.92 min shorter than the mean solar day.

To obtain the uncertainty in this value we have added to Figure 3.1 two further straight lines. These have also been obtained by hand-and-eye estimation, and give plausible upper and lower limits on the gradient of lines passing through (most of) the error bars. Their gradients are -4.05 min per crossing and -3.78 min per crossing. We thus have the final result: that the sidereal day is $3.9 \text{ min} \pm 0.1 \text{ min}$ shorter than the mean solar day – in satisfactory agreement with the accurate value of 3.93 min. Note the matching of the number of significant figures to the (rounded) uncertainty.

3.3 Summary of Section 3 and questions

- For numerical data always estimate the uncertainty, and write down values with a number of significant figures appropriate to the uncertainty. Always attach the physical units of a quantity.
- Make appropriate use of graphs to explore relationships between quantities and to obtain optimum numerical values.

Question 3.1

The angular diameter of the Moon is measured six times on a certain evening with equipment that has negligible systematic errors. The measured values are 31.2 arcmin, 31.1 arcmin, 31.4 arcmin, 31.5 arcmin, 31.1 arcmin, 31.2 arcmin. Obtain the mean value, and the uncertainty, and hence write down the outcome.

Question 3.2

Plot the following data on a graph, where time was more under control than observed angle between two objects in the sky. Obtain the rate at which the angle is changing with time, and the uncertainty in this rate. Is there any evidence for a change in the rate at which the angle is changing with time?

Time/s	0.0	10.0	20.0	30.0	40.0	50.0
Observed angle/arcsec	6.3	6.8	7.2	(obscured)	8.3	9.0

The uncertainties in time and angle are, respectively, $\pm 0.15 \text{ s}$ and $\pm 0.2 \text{ arcsec}$.

4 Writing an effective account of observational activities

For part of one of your TMAs you may be asked to produce a write-up of one of the activities. Any activity that will need to be written up will be specified in the relevant TMA. This section describes the approach to writing up an activity and an example write-up is provided in Appendix A.

4.1 Structure of a write-up

The details of a write-up will vary from activity to activity. However, for any of the S282 observational activities the sections which should be included and the order in which they should appear are given below, together with the approximate length required. Tables and diagrams are extra.

You should also:

- display on a separate line any equations that you use
- number any equations, tables, diagrams and graphs, and refer to them by their numbers
- give titles to all tables, diagrams and graphs.

However, you need *not* type your write-up.

4.1.1 Abstract

(100–200 words) This is a brief summary of the activity, concentrating on the main aim and the outcome. The abstract is preceded by the title, your name, and the date of completion of the write-up.

4.1.2 Introduction

(No more than about 200 words) Give the aim(s) of the activity, plus any astronomical background or context.

4.1.3 Observational (or measurement) procedure

(No more than about 500 words) Describe your observational site – but be very brief. Then, outline your observational method and the equipment you used. State any precautions you took to ensure success, and describe any difficulties you encountered. If manipulation of your raw observational data was called for, then describe what you have done. Do include diagrams if this is appropriate.

4.1.4 Results

(No more than about 500 words) Present your results clearly and concisely. If there are numerical data then present the raw data and also the values obtained after any data manipulation. Do include, as appropriate, dates, times, observational conditions, sketches, and unexpected events. Numerical quantities can be presented in tabular form or as graphs, or in both forms. Remember that a graph is a particularly useful way of showing the relationship between two quantities. All numerical data, and quantities derived from them, should carry estimates of the uncertainties in the values. The final outcome, be it one or more quantities (with their uncertainties) or qualitative statements, should be given *prominently*.

4.1.5 Conclusions

(100–200 words) Give any comments on the final outcome, plus any suggestions for improvements in the observing site/procedure/equipment/data manipulation.

4.2 Example of an observational activity write-up

4.2.1 Introduction

An example of an observational activity write-up (written by an imaginary student) is given in Appendix A. We hope this will be useful for you in deciding how to approach your own write-up for a future TMA. Although the example is *not* for one of the activities you will undertake, the principles of how to lay out a write-up are independent of the subject matter. All write-ups should stick fairly closely to the guidelines in Section 4.1. We have added comments on each section of the write-up, and indicated roughly how many marks each section would have got, and why. As you will see, this write-up has some flaws, which we hope you will avoid.

4.2.2 Background to the example activity

We have not produced a detailed activity instruction sheet, but for the purposes of this exercise you should assume that our imaginary student *was* provided with one. The activity instructions would have been to measure the varying length of a shadow cast by a vertical rod onto a horizontal surface, and to use these data to determine the time (in GMT) at the student's location when the Sun reached its highest point in the sky on a day near the June solstice.

The student would have been told to compare the time found by this method with the theoretical value.

There are two factors to take into account when calculating the theoretical time when the Sun should be at its highest:

First, you need to allow for longitude west of Greenwich as follows:

$$\text{local mean solar noon} = 12 \text{ h } 00 \text{ min} + (\theta / 360 \times 24 \text{ h})$$

where θ is longitude of the observing site west of Greenwich (θ takes a negative value for longitudes east of Greenwich).

Second, because the Earth's orbit about the Sun is elliptical rather than circular there is a slight and variable difference between mean solar time and actual solar time (see Section 1.3.1) such that

$$\text{actual local solar noon} = \text{local mean solar noon} + \Delta t$$

Corrections need to be applied as follows:

Date	Δt
11 June	−0 min 28 s
16 June	+0 min 34 s
21 June	+1 min 39 s
26 June	+2 min 43 s
1 July	+3 min 45 s

The imaginary student's write-up of this activity is given in Appendix A, together with our comments on what the student has done, section by section. To keep our comments separate we have put them in boxes. You will note also that this 'student's' report has been printed and illustrated to professional standards; of course, we do not expect real activity write-ups to look like this!

4.3 Summary of Section 4

- An activity write-up should be clear and concise, and should be organized under the following main headings: abstract; introduction; observational procedure; results; conclusions.

Now that you have finished reading this section, you should watch the video sequence 'Preparing for observing' before tackling any of the activities.

Answers to questions

Question 1.1

The stars are very nearly in opposite directions in the sky: the declinations have nearly equal magnitude and opposite signs, and the right ascensions are nearly 12 hours different.

Question 1.2

- (a) (i) The altitude of the north celestial pole, for an observer in the northern hemisphere, is the observer's latitude lat (see Figure 1.6).
- (ii) The zenith is vertically overhead, and so the altitude is $+90^\circ$. (*Note:* negative altitudes are below the horizon.)
- (b) The angle of the Sun from the zenith is given by $(+90^\circ 0' - 64^\circ 21')$, i.e. $25^\circ 39'$.

Question 1.3

At latitude 90° N, the celestial equator lies on the horizon; see Figure 1.19a.

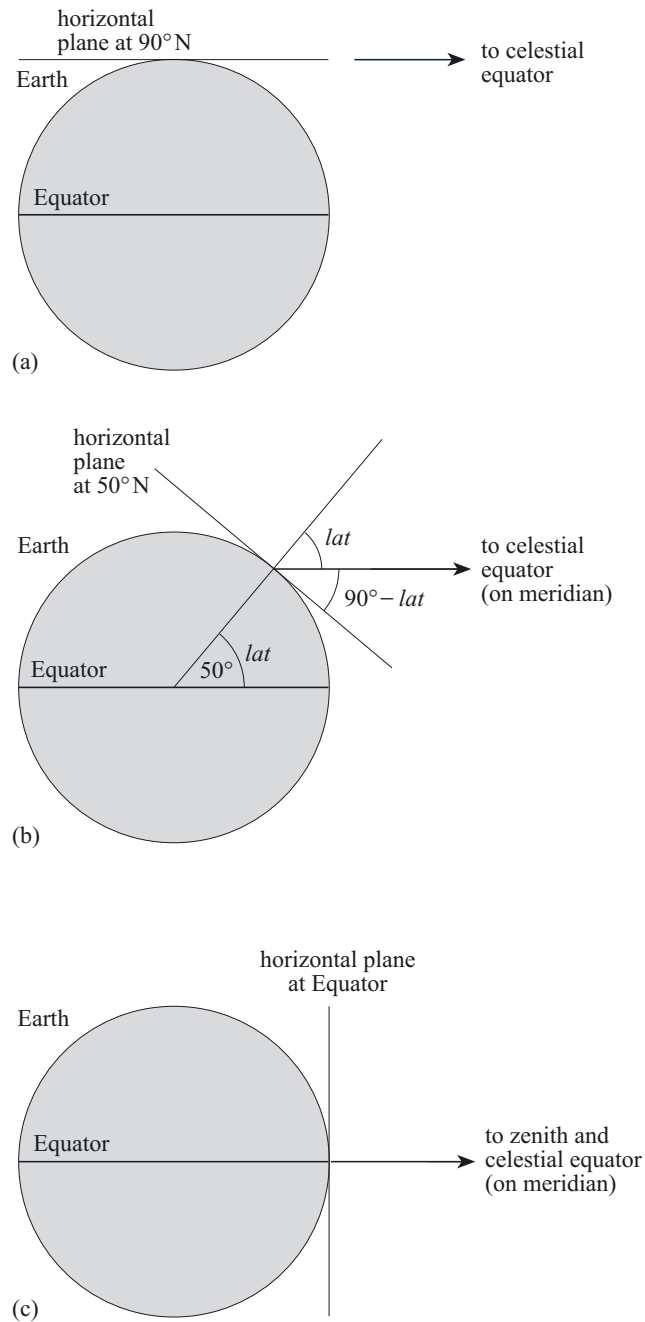


Figure 1.19

At latitude 50° N, the celestial equator meets the horizon at the east and west points (Figure 1.6). The celestial equator lies in the south, reaching a maximum altitude at the meridian, where the altitude is $(90^\circ - 50^\circ)$, i.e. 40° (Figure 1.19b).

At latitude 0° , i.e. the Equator, the celestial equator runs through the east and west points, and the zenith (Figure 1.19c).

(*Note: at any latitude away from the poles, the celestial equator meets the horizon at the east and west points (see Figure 1.6) and reaches a maximum altitude at the meridian, given by $(90^\circ - lat)$.*)

Question 1.4

(*Note: we assume that you have a planisphere for latitude $51\frac{1}{2}^\circ$ N. A star on the horizon should be positioned with its centre just covered by the red horizontal line.*)

- (a) (i) With Rigel on the eastern horizon, i.e. rising, the time that lines up with 18 February is a few minutes after 14 h: this is the mean solar time at which Rigel rises. Rigel is on the meridian at about 19 h 20 min, and sets at about 0 h 40 min (on 19 February).
- (ii) When Rigel rises on 18 February, the Sun is up, so it will be several hours before the Sun sets and Rigel, and the rest of Orion, becomes visible.
- (iii) On 5 March, Rigel rises at about 13 h.
- (b) At about 14 h on 18 February, the Plough is again on the meridian, but now to the north, between the north celestial pole and the northern horizon. (*Note: at latitude 55° N, the Plough is a circumpolar group of stars. Note that the Plough is a name for a prominent group of stars, and *not* the name of a constellation. The Plough is in the constellation Ursa Major, which means Great Bear (Figure 1.4).*)
- (c) We can select *any* date for the rising, and (if midnight passes) the subsequent date for the setting:
 - (i) Sirius: almost exactly 9 h
 - (ii) Aldebaran: almost exactly $15\frac{1}{2}$ h
 - (iii) Around 21 June, the Sun has a declination of about $23\frac{1}{2}^\circ$ (Figure 1.14).
The time between sunrise and sunset is then about 17 h 10 min.
(*Note: this is about the duration of the longest daytime at 55° N.*)

Question 2.1

The 7×30 pair is the more suitable, because it has the larger light-gathering power and because it more nearly meets the criterion $m \sim (D/\text{mm})/6$.

Question 3.1

The mean value is

$$(31.2 + 31.1 + 31.4 + 31.5 + 31.1 + 31.2) \text{ arcmin}/6$$

which works out to 31.3 arcmin. With $n/6 = 1$, we ignore one of the 31.1 arcmin values, and the 31.5 arcmin value. The range of the remainder is then 31.1 arcmin to 31.4 arcmin, and so the uncertainty is $(31.4 - 31.1) \text{ arcmin}/2$, i.e. 0.2 arcmin. We thus have $(31.3 \pm 0.2) \text{ arcmin}$ for the measured angular diameter of the Moon on the evening in question. The lunar orbit is slightly elliptical, and so the distance of the Moon from the Earth varies. Consequently, the angular diameter of the Moon varies during the month from 33.5 arcmin to 29.4 arcmin.

Question 3.2

This graph is shown in Figure 3.2. Note that the error bars in time are too small to show. Our best-fit straight line is the solid one, and it has a gradient of $2.12 \text{ arcsec}/39.6 \text{ s} = 0.054 \text{ arcsec s}^{-1}$. The upper and lower limits, the fainter lines, have gradients of $0.060 \text{ arcsec s}^{-1}$ and $0.048 \text{ arcsec s}^{-1}$. Thus, the angle is changing with time at a rate of $(0.054 \pm 0.006) \text{ arcsec s}^{-1}$. There is no evidence of any departure from a straight line relationship, and hence no evidence for a change in this rate. (*Note: any best-fit gradient between 0.051 and $0.057 \text{ arcsec s}^{-1}$ will do, and any uncertainty between ± 0.004 and $\pm 0.008 \text{ arcsec s}^{-1}$.*)

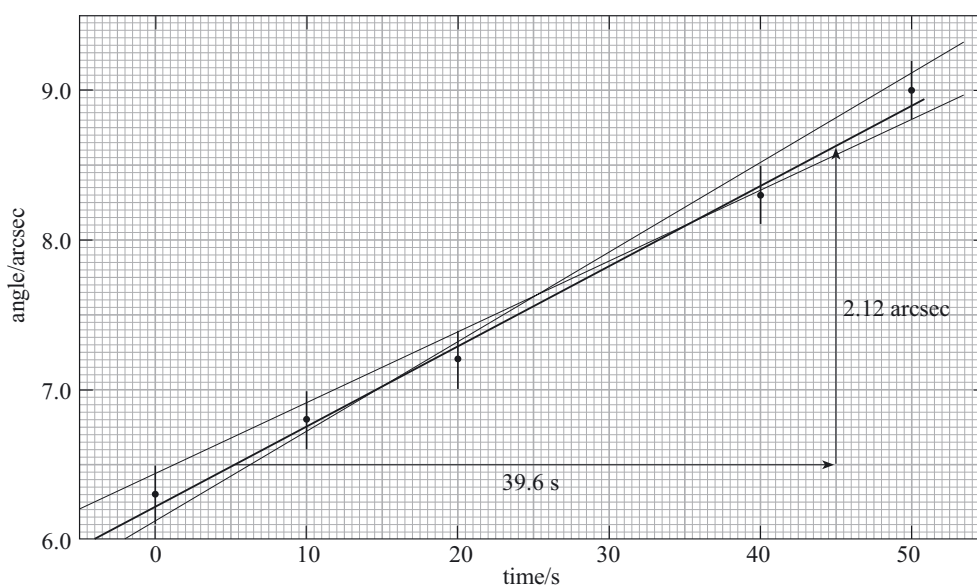


Figure 3.2

Acknowledgements

Figure 1.9, David Parker/Science Photo Library

Appendix A: a sample write-up

A determination of local time

Abstract

The time of midday at Edinburgh was determined from measurements of a shadow cast by a post. The result of 12 h 17 min GMT ± 3 min is slightly ahead of the theoretical value of 12 h 12 min 56 s but improvements to the method could enable a more accurate determination to be made. Comparisons are made with observations reported from the school of astronomy at Alexandria in 235 BC.

Abstract The activity is summarized, and outcome is stated, together with the estimated uncertainty in this value. We have therefore awarded full marks, even though the *aim* of the activity could have been stated more explicitly with a statement along these lines: ‘The aim of this activity was to measure the time of midday.’ or (better) ‘... the time when the Sun reached its highest point in the sky’. The first sentence would have been better as follows: ‘The time of midday at Edinburgh was determined by finding when the length of shadow cast by a post was shortest ...’ as this gives more information about how the aim was achieved.

Marks: 4/4

Introduction

In a famous set of observations, Eratosthenes measured the length of a shadow cast by a post on the June solstice. From this he calculated the elevation of the Sun, and with knowledge of his distance from the tropic of Cancer he estimated the radius of the Earth.

As the Sun moves across the sky it reaches its culmination point at noon, and shadows are at their shortest. In this reconstruction of Eratosthenes’ experiment, the civil time t_{obs} of local noon is found from measurements of shadow lengths l cast by a post either side of midday. This provides an independent check on Eratosthenes’ method because the time of local noon can also be calculated from the known longitude of Edinburgh.

Figure A1 shows the position of the Earth in relation to the Sun on the June solstice. Edinburgh (E) is shown on a great circle that passes through the poles (a line of constant longitude).

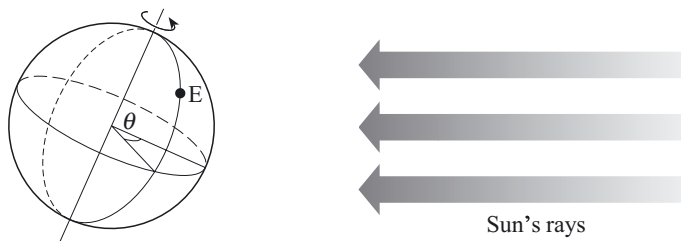


Figure A1 Position of the Earth at 12.00 GMT on the June solstice.

At 12.00 GMT, locations on the Greenwich meridian (0° of longitude) experience local noon. But places on a great circle of longitude $\theta^\circ\text{W}$ will experience their noon at

$$t_{\text{th}} = \left(\frac{\theta}{360^\circ} \times 24 \right) + 12 \text{ h } 00 \text{ min} \quad (1)$$

Since the post is cylindrical, estimation of the base of the shadow was straight forward, but because the Sun's rays are not quite parallel, blurring of the shadow tip made end estimation quite difficult. Figure A2 shows the observational site and Figure A3 shows an impression of the shadow tip.

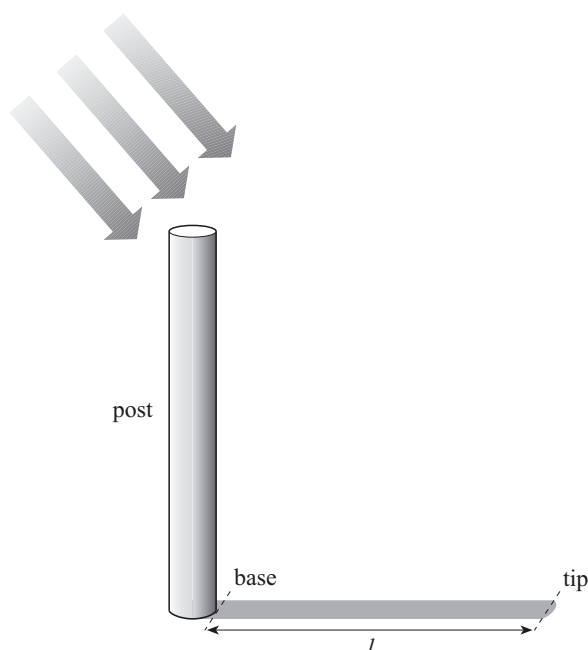


Figure A2 Observational site.

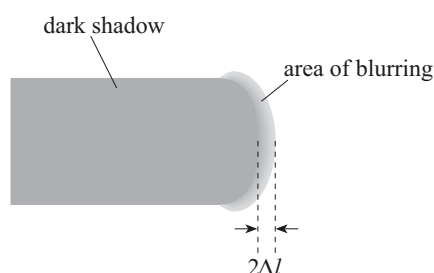


Figure A3 Close up of shadow tip.

The length l was measured from the base to the middle of the blurred region along with the uncertainty $\pm \Delta l$ indicating the region in which it was sure the shadow tip lay.

The aim of this set of observations is to measure t_{obs} and by comparison with t_{th} to comment on a remarkable result of the Alexandrian astronomers.

Introduction This section mixes in the observational procedure (including diagrams and estimation of the uncertainty, Δl), which should be in the next section (no marks penalty in this section, but it will result in a marks penalty in the next section). However, it does give both *background*, including Figures A1 and A2 and a nice mention of use of a similar technique by Eratosthenes, and the *aims* of the activity. But perhaps it leaves the reader a little confused; is the activity supposed to measure length of shadow in order to determine latitude (which is effectively what Eratosthenes did in using shadow lengths at noon to measure the radius of the Earth), or is it to measure the time (in GMT) when the shadow length is shortest? In fact, only the latter is attempted in this activity.

Marks: 6/7

Observational procedure

Preliminary observations suggested that a post of height 2–3 m would be needed to (a) cast a shadow with significant length variation yet (b) could still be accurately measured with a steel tape measure. Eventually, a post – probably once indicating parking restrictions – satisfying (a) and (b) was found in a quiet location. A wide flat pavement to the north of the post enabled measurement of the whole shadow.

In fact the June solstice was sunny and bright and this day was chosen for observations.

A quartz clock was synchronized by the BBC radio time signal and the length l of the post's shadow was measured with a steel tape measure at intervals of a few minutes over a period of about $1\frac{1}{4}$ hours either side of local noon.

Weather conditions were noted during the course of the measurements, as was the unexpected arrival of a shadow from a nearby street light.

The post was checked to be vertical with a spirit level.

The clock was set to British Summer Time (BST) by the BBC time signal just before measurements and synchrony was checked again four hours later. A subtraction of exactly one hour is needed to convert to GMT.

Observational procedure Site described, difficulties described (but not all; see next section), note about conversion from BST to GMT included. Diagrams (Figures A2 and A3) in previous section will be credited here, but style marks deducted for mislocating them to the Introduction. *Marks: 12/15*

Results

Date of measurement: 21.06.02

Weather conditions: Mostly sunny, with very clear air (little moisture) but some high cumulus cloud.

Quartz clock set to within ten seconds of time signal at 11.00 BST and was found to be 30 seconds fast at 15.00 BST. Since there is also some uncertainty in comparing the time to exactly when l is estimated, uncertainty in t is taken to be $\Delta t = \pm \frac{1}{2}$ min for all measurements.

Post height: (229.6 ± 0.2) cm.

Post checked to be vertical within the limits set by a domestic spirit level.

It was noted that although the pavement appeared to be flat there was a small dip to the north east.

The results for l , Δl and t along with comments are compiled in Table A1.

The data from Table A1 is plotted in Figure A4.

Table A1 Recorded data with comments.

<i>l</i> /cm	Δ /cm	<i>t</i> /h min BST $\pm \frac{1}{2}$ min	Comments
154.5	0.5	12.03	bright conditions
150.75	0.5	12.12	bright conditions
148.5	0.5	12.20	bright conditions
—	—	12.25	large cloud overhead
146.5	1	12.30	hazy
143.0	1	12.46	hazy
142.0	1	12.49	hazy
143.0	1	12.56	hazy
139.5	0.5	13.05	bright conditions
140.5	0.5	13.07.30"	bright conditions
139.75	0.5	13.10	bright conditions
139.5	0.5	13.12	bright conditions
139.5	0.5	13.15	bright conditions
139.5	0.5	13.18	bright conditions
140.0	0.5	13.22	bright conditions
140.0	0.5	13.25	bright conditions
140.0	0.5	13.30	bright conditions
—	—	13.31	large cloud overhead
140.75	0.5	13.39	bright conditions
142.0	0.5	13.45	bright conditions
142.5	0.5	13.50	bright conditions
—	—	13.51	Large cloud overhead
—	—	14.04	cloud clears, but shadow from lamp post obscures pole's shadow
148.0	0.5	14.10	bright conditions
149.5	0.5	14.15	bright conditions
151.5	0.5	14.20	bright conditions
153.0	0.5	14.25.30"	bright conditions

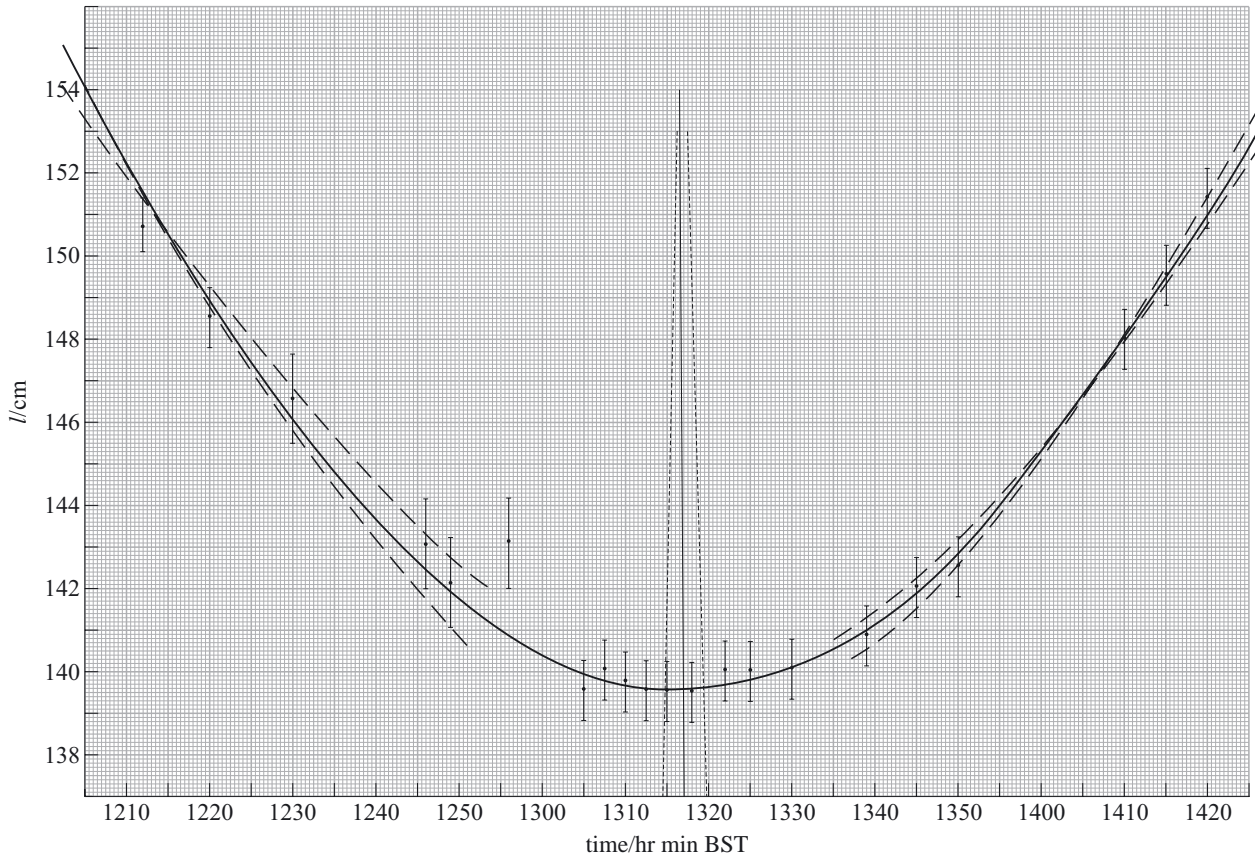


Figure A4 Plotted data from Table A1.

The total uncertainty in l (vertical error bar) is a combination of Δl and an additional uncertainty Δx which results from uncertainties in measuring the base of the shadow and any effects due to pavement unevenness. Hence,

$$\text{total uncertainty in } l = \sqrt{\Delta x^2 + \Delta l^2} \quad (2)$$

using the method of reference 1.

The graph illustrates the difficulty in estimating minima. A method was devised that uses data from the plot where the rate of change is appreciable. A smooth curve (bold line) was drawn through the error bars and as close to the actual data points as possible. The point at 12.56 was assumed to be bogus. The comments show that hazy conditions prevailed at this time. Horizontal lines were then drawn across the curve and the best perpendicular bisector projected onto the time axis to provide an estimation of t_{obs} . This method involves all data points and assumes symmetry. Some measure of the uncertainty in t_{obs} is obtained by applying this technique to other curves that could be reasonably drawn through the error bars. Extremes are drawn as broken lines in Figure A4.

This method provides a figure

$$t_{\text{obs}} = 12 \text{ h } 17 \text{ min } \pm 3 \text{ min GMT}$$

and using a figure of $\theta = 3^\circ 14' \text{ W}$ (ref. 3) and Equation 1

$$t_{\text{th}} = 12 \text{ h } 12 \text{ min } 56 \text{ s GMT}$$

Results Date and observing conditions given here. Raw data presented excellently in a table, with estimates of uncertainties. Data shown in graphical form, with labelled axes. Δx is introduced without discussing how to estimate it, but all other experimental uncertainties are well handled. It might have been better to discuss the flatness and levelness of the pavement in the previous section (along with the verticalness of the post). Note that in a write-up you are not obliged to discuss things in the order in which they occurred to you! Traditionally, write-ups give the impression of perfect foresight, and flawless performance of the experiment! They are written in this way for the very good reason that a clear, well-organized *account* communicates what you did much more effectively. (Slope of surface is important if latitude is to be measured, but not if the only aim is to determine the time when shadow length is minimum.)

The method of perpendicular bisectors is the appropriate way to determine the position of the minimum (were this a real activity, we would have described this method in Section 3. You *never* need to refer to sources outside S282 to answer any question, or to attempt any activity, but you are free to do so if you wish). The ‘extremes’ are used appropriately to determine uncertainty in t_{obs} . There is a minor inconsistency in the quoting of units of time with ‘h’ and ‘hr’ used for hours. This example does not affect the results or our understanding. However, it is important to be consistent with nomenclature and units to avoid possible confusion or errors.

The imaginary student has made an error in calculating the theoretical time of local solar noon. The equation to correct for longitude is correctly applied, but the student has forgotten the second correction to convert from mean local solar noon to actual local solar noon (Δt in the table in our introduction to the activity). As a result, 1 mark out of 3 for the calculation of the theoretical time of local solar noon is lost (allowing for Δt , t_{th} becomes 12 h 12 min 56 s + 1 min 39 s = 12 h 14 min 35 s, which is a bit closer to t_{obs} , and in fact just inside the degree of uncertainty estimated by the student). However, because (i) the *layout* of this section is good, (ii) the *style* is fairly clear, and (iii) the *handling of the observation data* is excellent, the overall marks for this section are good.

Note that there is no significant penalty for getting a ‘wrong’ value in a result (provided you realize that it is wrong). Most of the marks are for the way you collect the data, whether or not you handle the data appropriately, and how clearly you describe what you have done. *Marks: 15/17*

Conclusions

The earliest time of noon at Edinburgh according to this data and analysis is still one minute ahead of the theoretical value. It is possible that a more sophisticated analysis – rather than curve fitting ‘by eye’ – would give better agreement. Alternatively, the uncertainties may be underestimated. If the pavement does indeed tilt away from the horizontal then shadow length would vary for the same elevation of the Sun. This, though, would be revealed in a skew-plot, which was not found. However, the uncertainty Δx may be too low.

It is difficult to see how the inherent problem of tip blurring can be overcome, but if observations are made over a longer time period, and more frequently, especially where the rate of change of l is greater, accuracy could be improved.

It would also be beneficial to have cloudless conditions and no crossings from other shadows!

Despite these limitations, Eratosthenes' method appears to be sound, although this astronomer doubts if he could attain 5% uncertainties.

References

- 1 The Open University, S282 activity 'Stellar distance and motion', pub. 2003
- 2 Odhams New Atlas of the World, pub. 1957.

Conclusions Comments on the value found (in this case the time of actual local solar noon) are given, together with a brief discussion on the possibility for improving the method. It would have been worth commenting on whether a more reliable set of data could have been collected using a longer post or a shorter post, and following through on the tip blurring problem by exploring (or at least wondering) whether the width of the post, or the shape of the top of the post has any bearing on the results. Eratosthenes' experiment is similar to the experiment here only in that it used similar apparatus; Eratosthenes' aims were different, namely to measure the radius of the Earth from shadow-lengths at noon at different latitudes. However, the comment about his experimental uncertainties is valid.

Adding references is useful to indicate from where particular information has been obtained. However, reference 2 is not cited anywhere in the text so it is not clear what it was used for.

Marks 6/7

Total marks for this write-up: 43/50

Observational activity instructions

Preparing for observing

Study time: 20 minutes

Summary

This video sequence complements the written material in the *Observational activities* booklet. It explains the use of the planisphere, how to tackle an observational project using ‘The sidereal and solar day’ as an example, and provides animations of the sky’s apparent motion.

Learning outcomes

The learning outcomes for the observational activities are grouped together at the front of the *Observational activities* booklet.

Pre-viewing notes

There are two parts to the sequence:

- a demonstration of the use of the planisphere, and of how to tackle the observational activity ‘The sidereal and solar day’ (4.5 minutes)
- an animation of the sky’s apparent motion (6 minutes).

Note that this video sequence was prepared before this course was written so there are a few small anomalies with the content:

- The label ‘1’ in the top left of the screen can be ignored.
- The elapsed time in the top right of the screen has some small gaps.
- The presenter refers to ‘project book’, ‘project sheets’ and ‘this videotape’ which should be regarded as ‘activity notebook’, ‘observational activity instructions’ and ‘this video sequence’ respectively.

The activity

- To find the video clip for this activity, start the S282 Multimedia guide and then click on Preparing for observing under the Observational activities folder in the left-hand panel.
- Press the Start button to run the video sequence.

Post-viewing notes

The *Observational activities* booklet and observational activity instructions contain material that fully supports this video sequence so no further material is given here. The animation can usefully be compared with Figures 1.5 and 1.6 in the *Observational activities* booklet.

Video credits

Presenter – Barrie Jones (The Open University)

Producer – Tony Jolly (BBC)

In and around Orion

Study time: 90 minutes

Summary

In this observational activity you will perform and record some simple observations of various celestial objects in and near the prominent constellation, Orion.

You should study the *Observational activities* booklet and view the video sequence 'Preparing for observing' before undertaking this activity. You should do this activity before 'Limiting visual stellar magnitudes', although both of these activities can be done during the same observing session.

The study time indicates how long you will need for the observing session(s) and includes preparation and note taking; the observations themselves should take less time. Data analysis and writing up require additional time after the observing session.

Learning outcomes

The learning outcomes for the observational activities are grouped together at the front of the *Observational activities* booklet.

Preparation

The greater the altitude above the horizon of a celestial object, the less are the effects of atmospheric extinction (the reduction in the light reaching you from a celestial body, as a result of absorption and scattering in the atmosphere). The effects of light pollution also diminish with increasing altitude (light pollution is light, usually from ground level, scattered downwards by small liquid and solid particles in the atmosphere). Therefore, try to make your observations when Orion is close to its maximum altitude, i.e. within a couple of hours or so of crossing/having crossed your meridian: use your planisphere to plan your observing time.

Also, avoid making observations when the Moon is between first and third quarters, or in the same general direction as Orion. Moonlight increases the level of light pollution.

When you go to your observing site to do this activity, you will need to take:

- the planisphere and, if not identified already, a means of identifying north (such as a magnetic compass)
- these activity notes
- a torch (flashlight)
- a clear plastic 30 cm ruler, marked in millimetres
- your activity notebook plus something to write with.

Though a useful fraction of this activity can be completed without binoculars, if you have access to binoculars then do take them with you.

Observations

1 Your first task is to find Orion. On the planisphere it is centred on the celestial coordinates (5 h, 0°). On site, identify the northerly direction, and use the planisphere to identify roughly where you should look to see Orion. You might spot Orion at once, particularly if you have any experience at constellation spotting. Less experienced observers should find Figure 1 of help. If you hold it

at arm's length in front of you (about 600 mm from your eye) then this is the pattern that the main stars in Orion form, at about the correct angular separations.

2 Measure the angular separation (in degrees) between Betelgeuse ('betel-jers') and Rigel ('rye-jel'), the two most prominent stars in Orion (Figure 1). One way of doing this is to hold a clear plastic ruler at arm's length against the sky, using the torch (perhaps dimmed) to illuminate the scale. This method is outlined in Figure 2 (*overleaf*). If the ruler is a distance d from the front of your eye (Figure 2), then the angle α between two objects separated by h on the ruler is given by

$$\alpha/\text{radians} \approx h/d$$

or

$$\alpha/\text{deg} \approx 57 \times (h/d) \quad (1)$$

This approximation is sufficiently good for this activity, up to $\alpha \approx 20$ deg. (It gets worse as α increases, because the ruler is not following the circle centred on your eye – shown as the curved line in Figure 2.) In your activity notebook, outline your method and record your values of h , d and α .

You must now calculate the *uncertainty* $\Delta\alpha$ in α . This depends on your estimates of the uncertainties Δh and Δd in h and d .

First, calculate $\alpha_{\text{max}}/\text{degree} \approx 57 \times (h + \Delta h)/(d - \Delta d)$

then calculate $\alpha_{\text{min}}/\text{degree} \approx 57 \times (h - \Delta h)/(d + \Delta d)$

We then have the uncertainty in α :

$$\Delta\alpha/\text{degree} \approx (\alpha_{\text{max}} - \alpha_{\text{min}})/2 \quad (2)$$

This rough and ready method will do for our purposes. Record the details of your calculations in your activity notebook.

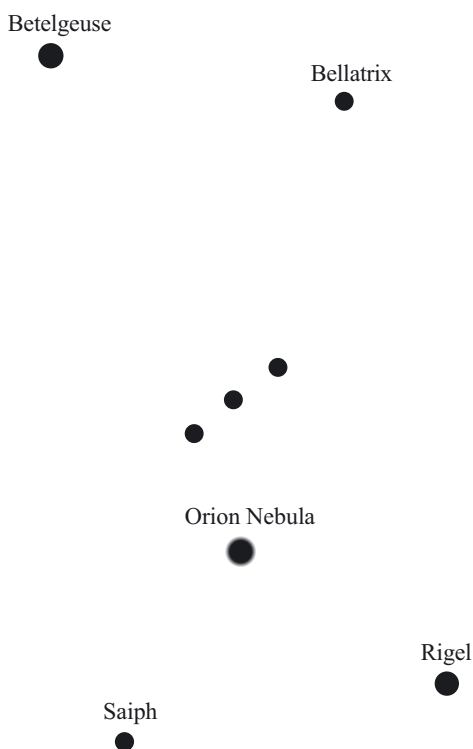


Figure 1 The main stars in Orion.

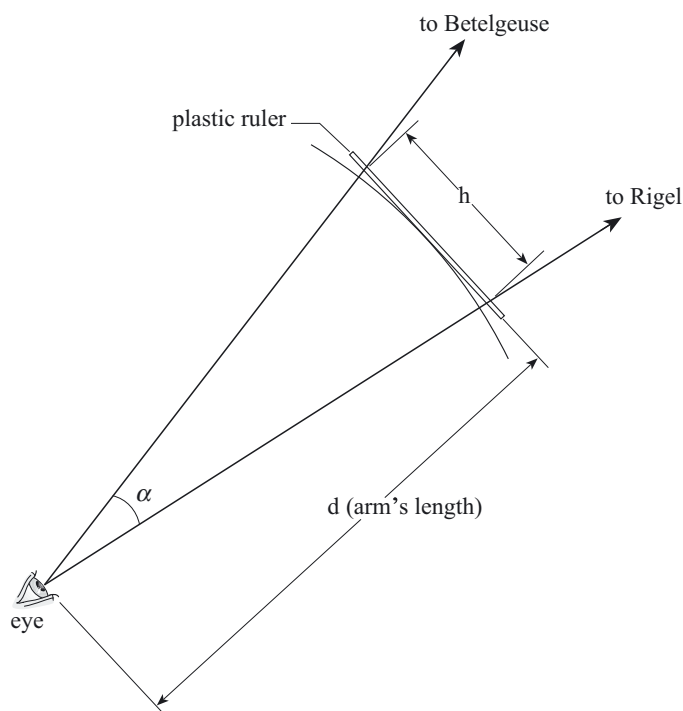


Figure 2 Obtaining angular separation.

3 Compare the colours of the stars Betelgeuse and Rigel with the unaided eye. If you have binoculars, then try defocusing them very slightly – this might help to show the colour difference. Record your observations and state whether they are in accord with the surface temperatures of these stars given in Table 1. (Note that Rigel is a double star, but we only really see the brighter, Rigel A. You will meet Rigel and Betelgeuse again in Chapter 3 of *An Introduction to the Sun and Stars*.)

Table 1

Star	Luminosity/ L_{\odot}	Temperature/K
Betelgeuse	100 000	3500
Rigel	140 000	13 000

4 If the sky is dark and clear, then, with the unaided eye, try to spot the Orion Nebula (Figure 1) – part of a massive dense cloud, lit by the very young stars born in the cloud less than a million years ago. To the unaided eye it looks like a faint star, but binoculars reveal a small, fuzzy patch – not as glorious as Figure 4.13 in *An Introduction to the Sun and Stars*, but distinctly non-stellar! Even if the sky is so bright that the Orion Nebula is invisible to the unaided eye, it may still be visible with binoculars. Describe briefly what you can see with the unaided eye and binoculars; include a sketch if this is helpful.

The following observations are of particular interest if you have access to a pair of binoculars. If not, you may still wish to observe using the naked eye.

5 With the aid of a planisphere, find the star cluster known as the Pleiades ('ply-a-dees'), which is centred on (3.7 h, +24°). With the unaided eye this cluster might appear only as a fuzzy patch, although in a dark sky up to seven stars (the Seven Sisters) might be discernable. With binoculars, many tens of stars will be seen. The Pleiades is an open cluster, and contains several hundred stars, all fairly young. Describe briefly what you see, with and without binoculars. Hence write down the improvements that your binoculars bring to your view of the Pleiades.

6 Finally, if the sky is dark and moonless, then even with the unaided eye you should be able to see the Milky Way, between Orion and the north celestial pole (see the planisphere). The Milky Way is a broad band of light that is our edgewise view through the Galaxy. With binoculars the band will be resolved into myriads of stars. Follow the Milky Way with your binoculars until you reach the region of the constellation Perseus around (3 h, +50°). This is a particularly rich area. Describe briefly what you see, with and without binoculars. Have your binoculars brought about the same improvements as when you used them to view the Pleiades?

Limiting visual stellar magnitudes

Study time: 1 hour

Summary

In this observational activity you will investigate the limiting visual stellar magnitude at your chosen observing site, preferably in a variety of atmospheric conditions. (As an ‘optional extra’, you can compare two different sites.) This will be performed by visual observations of stars in the constellation of Orion.

You should do this activity after you have completed ‘In and around Orion’, although both of these activities can be done during the same observing session.

The study time indicates how long you will need for the observing session(s) and includes preparation and note taking; the observations themselves should take less time. Data analysis and writing up require additional time after the observing session.

Learning outcomes

The learning outcomes for the observational activities are grouped together at the front of the *Observational activities* booklet.

Introduction

The limiting visual stellar magnitude, \hat{V} , is the apparent visual magnitude, V (see Section 3.3.3 in *An Introduction to the Sun and Stars*), of the faintest star that you can see with the unaided eye. It helps define the quality of a site for astronomical observations. This limit is determined by three things:

- 1 Atmospheric extinction. This is the reduction in light reaching you from a star as a result of absorption and scattering in the atmosphere. Normally, the greater the altitude of the star, the less the degree of extinction.
- 2 Light pollution. This is light, usually from ground level, scattered back downwards by small solid and liquid particles in the atmosphere. Again, the greater the star’s altitude, then, normally, the less the light pollution.
- 3 Your eyes! We do differ from each other in our ability to detect faint stars. Moreover, a person’s left and right eyes are likely to differ. Do use your better eye.

Note that light pollution and atmospheric extinction vary from site to site, with the weather, and with the level of any human activity that generates solid and liquid particles, e.g. transport, industrial processes.

Preparation

Try to be on site when Orion is near its maximum altitude, that is within two hours of it crossing/having crossed the meridian – use your planisphere *before* you set off, to decide whether Orion will meet this condition when you are on site. Avoid making observations when the Moon is up, unless it is only a thin crescent at low altitude: you need conditions to be as dark as possible.

When you go to your observing site to do this activity, you will need to take:

- these activity notes
- a torch (flashlight)
- your activity notebook, plus something to write with.

Observations

We suggest that you estimate \hat{V} in Orion, in each of the two regions of the sky marked A and B in Figure 1 (*overleaf*), which shows stars down to $V = 6$, about the limit for human vision at a *good* site in *good* conditions. Before you make each estimate of \hat{V} , allow your eyes at least 5 minutes to become adapted to the (low) light conditions under which you will make your estimate.

- 1 For region A, near Betelgeuse, use Figure 1 to estimate \hat{V} . Estimate also the uncertainty in \hat{V} . Obtain the corresponding estimates for region B, near Rigel. Record both values and the uncertainties in your activity notebook, along with the approximate altitude of each region, the date and time, details of the site, and details of atmospheric conditions and light pollution. Record any other pertinent observations.

Note: in estimating \hat{V} , you might notice the benefit of averted vision (see Section 2.4 in the *Observational activities* booklet). Indeed, the above-mentioned limit of $V = 6$ normally requires averted vision. Try to obtain your estimates of \hat{V} by using averted vision. Record whether you do use averted vision.

- 2 Repeat step 1 on at least one other occasion, when atmospheric conditions or light pollution are different.
- 3 You can also repeat the project at a different site, though this is very much an ‘optional extra’.

After you have made your estimates of \hat{V} , write some brief comments about the quality of the site under the various atmospheric conditions, and the degree of light pollution.

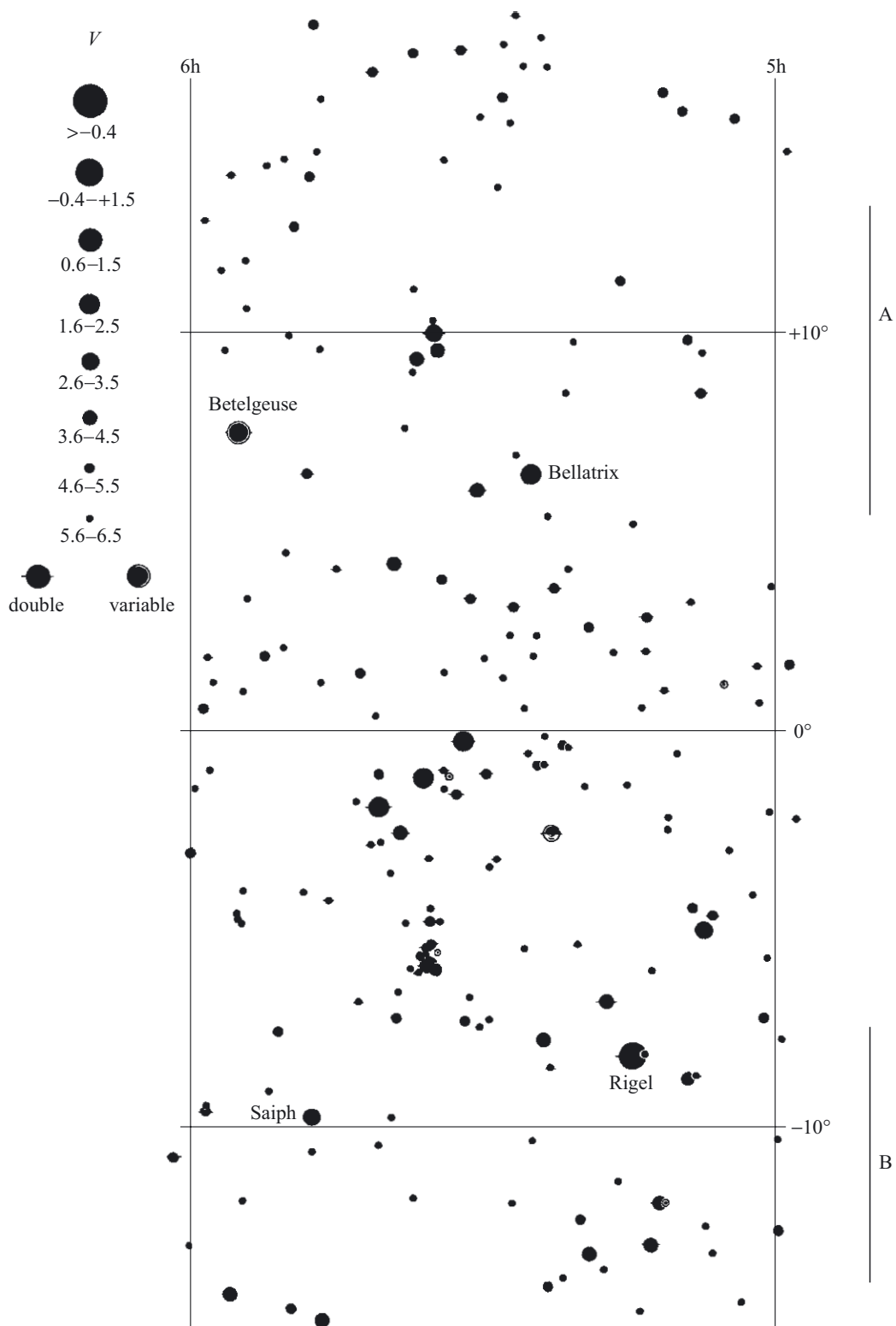


Figure 1 Stars in Orion, down to $V=6$.

The sidereal and solar day

Study time: 2 hours

Summary

In this observational activity you will measure the difference in length of time between the sidereal day, as kept by the stars, and the mean solar day, as kept by an ordinary watch, by observing the civil time at which a star crosses a fixed direction in your sky on different dates.

The background to this activity is described in Section 1.3.1 of the *Observational activities* booklet. The video sequence 'Preparing for observing' also provides help, and you should watch it before you take any measurements.

The study time indicates how long you will need for the observing session(s) and includes preparation and note taking; the observations themselves should take less time. Data analysis and writing up require *additional* time after the observing session.

Learning outcomes

The learning outcomes for the observational activities are grouped together at the front of the *Observational activities* booklet.

Preparation

You should do the activity 'In and around Orion' before you do this one.

You need to choose a star and a reference direction. In principle, *any* star and *any* reference direction will do, but there are some practical considerations. Consider the star. It needs to be bright and easy to find. Also, a star nearer the celestial equator will move across the sky through a greater arc in a given time than a star away from the equator, thus allowing better precision in the timing. Therefore, choose a bright star not very far from the celestial equator. For February or March evening observations, Betelgeuse and Rigel in Orion are suitable. For other dates and times you will have to use your planisphere to select a suitable star.

The reference direction is set by a fixed observing position and a fixed terrestrial object located between this position and the star. For the object, some kind of edge is strongly recommended. Avoid edges that the star will cross at a grazing angle – the precision of the timing would then be very poor. A vertical edge of a building is a very suitable object, and it should be at least 20 metres away to ensure adequate measurement precision. For example, the chimney in Figure 1 (*overleaf*) is a very suitable object. (The discussion here of the choice of reference direction assumes that the observer is well away from the Earth's Equator, that is the observer is at a latitude where stars near the celestial equator do not rise very high in the sky.) In this particular case, the observing position is fixed by the observer leaning the head against a particular spot on a wall, and making all observations with the same eye. The star is then seen to pass behind the chimney at intervals of one sidereal day.

For a given star and given date, the civil time at which the star is in the reference direction depends on your particular choice of reference direction. It is advantageous if this direction is within 30 degrees or so of due south, because the star is then not far from its highest altitude, and will be less dimmed by atmospheric extinction and less likely to be hidden by terrestrial objects.

Finally, it is convenient to see the star approach the edge, rather than emerge from behind it, and so it is better to use the eastern edge of an object rather than the western edge.

Whatever your choices of star, edge and observing position, do ensure that you record your choices in your activity notebook – you will need to make all timings from the same observing position, using the same star and the same edge.

When you go to your observing site to do this activity, you will need to take with you

- these activity notes
- a torch (flashlight)
- a watch, set to the nearest few seconds (using the telephone, or a radio time signal)
- your activity notebook, plus something to write with.



Figure 1 The chosen star approaches the reference edge (the chimney stack).

Making measurements

You need to measure the time at which the star crosses the edge on at least three nights (although four or five nights would be far better) spread over two to five weeks. Use your planisphere to help you decide roughly when you should arrive on site: if daylight saving time is in force (in the UK after late March), then remember to subtract an hour to obtain the time shown on the planisphere.

At your observing site, place your head in as repeatable a position as possible. In Figure 1 this is achieved by leaning against a particular spot on the wall. Also, always observe the star with one eye, the same eye each time – your eyes are about 0.07 m apart, which corresponds to an angle of about 0.2° at 20 m, which can give a timing error of nearly a minute.

You will have plenty of time to observe the star's approach to the edge. Even for a star near the celestial equator, as the Earth rotates, the star will appear to move

west at only about 1° in 4 minutes. However, such slow progression does mean that, without optical aid, the time at which the star crosses the edge cannot be measured very precisely. The main problem is slight movements of the head. These will cause the star to bobble in and out of view: the closer the edge, the larger the apparent random stellar motions, and the longer for which the bobbling carries on. The time to be recorded in your activity notebook is that at which the star is in view roughly half the time. You must also record your estimated uncertainty in this time. A large uncertainty means that, if you carry out observations on successive nights, it might be difficult to discern any difference in the crossing times. However, by spreading at least three observations over at least two weeks, you will be able to obtain a reasonable value for the difference in length between the sidereal day and the mean solar day.

Data analysis

To obtain the difference in length between the sidereal and solar days, and its uncertainty, if you have at least three observations, you should follow the graphical method in Section 3.2 of the *Observational activities* booklet. If, unfortunately, you have only two observations, a simple calculation will suffice.

You may wish to use your value for the difference in length of day to predict the crossing times in the days to come, and then you could check your predictions.

The luminosity of the Sun

Study time: 90 minutes

Summary

In this observational activity you will perform an experiment to measure the luminosity of the Sun by comparing its brightness with that of a light bulb.

Warning Remember it is **very dangerous** to look directly at the Sun and on no account should you look at the Sun through any telescope or binoculars. Otherwise, you will suffer permanent eye damage, and perhaps blindness.

The experiment requires use of a *clear tungsten filament* light bulb of at least 100 W (it will not work with other types of bulb). These bulbs have been withdrawn from sale in the UK and you may therefore not be able to do the experiment yourself. However, an alternative online interactive version of this experiment will be available on the course website. If you perform the online version, you should still read all the notes (Introduction, Preparation and Making measurements sections) for the practical activity first so that you fully understand the experiment. The online version will provide instructions for taking measurements using the virtual experiment apparatus. The data analysis is the same for both experiments.

The luminosity of the Sun is its power output over all wavelengths and over all directions, as explained in Sections 1.2.1 and 1.4.2 of *An Introduction to the Sun and Stars*.

You should study the *Observational activities* booklet before undertaking this activity.

The study time indicates how long you will need for the observing session(s) and includes preparation and note taking; the observations themselves should take less time. Data analysis and writing up require additional time after the observing session.

Learning outcomes

The learning outcomes for the observational activities are grouped together at the front of the *Observational activities* booklet.

Introduction

A clear sky for only about one hour is required, and you will not need binoculars.

The luminosity of the Sun is measured by comparing it with a source of known luminosity, such as a tungsten bulb. The set-up is shown in Figure 1. When you view the sheet of paper from the Sun-facing side, the brightness of the oil-spot on the sheet depends on the flux density (illumination) provided by the tungsten bulb, and the brightness of the oil-free paper surrounding the spot depends on the flux density provided by the Sun. The distance, d_b , between the sheet and the bulb is varied until the oil-spot looks about as bright as the surrounding paper. The distance of the sheet from the bulb filament is then measured, and the solar luminosity calculated. An oil-spot used in this way constitutes what is known as Bunsen's oil-spot (or grease spot) photometer, named after the German scientist Robert Bunsen (1811–1899).

Further details follow – read through them all before you start.

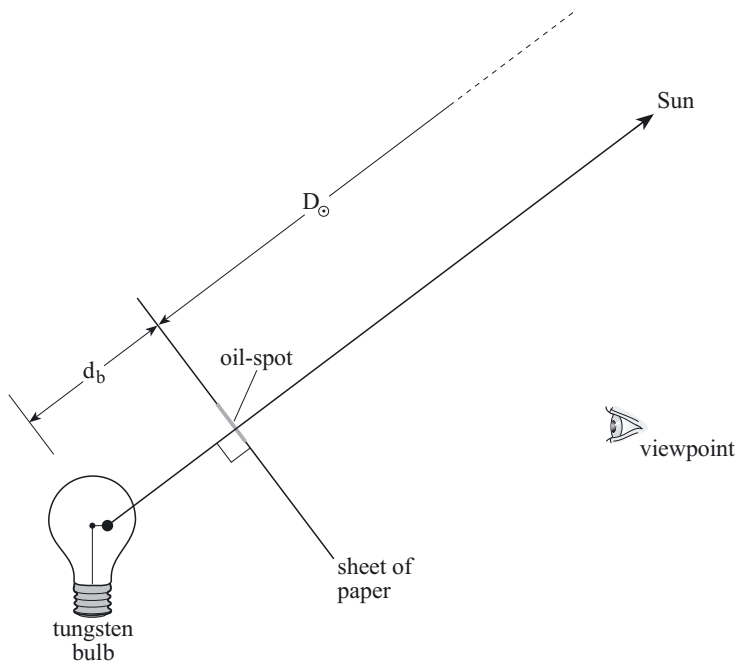


Figure 1 The observational set-up.

Preparation

You need a light source of known luminosity. A *clear* (not pearl) mains-operated *tungsten filament* bulb of 100 W (or better, a 150 W bulb if you can find one) is required for this experiment. The bulb has to be located out of doors, or near an open window through which the Sun shines. A table lamp with the shade removed makes an excellent receptacle for the bulb.

Do take care with mains electricity, particularly if you are working out of doors. Also, note that the bulb will get hot.

The next task is to obtain the sheet of paper used to compare the two flux densities. The paper must be white, un-ruled, non-glossy, and of normal thickness – just the sort of paper commonly sold in pads in stationery shops or newsagents. A4 size is suitable.

When you are ready to make observations, put a spot of oil near the centre of the sheet. The spot must be no more than about 4 mm diameter. You can prepare the oil-spot by dipping a skewer in cooking oil, then removing nearly all the oil with a tissue, and then touching the skewer tip on the sheet for just an instant. The oil-spot tends to spread, and so it should be prepared within about an hour of when you want to use it.

Next, you need some means of holding the sheet steady, fairly near to the bulb, and roughly at right angles to the line from the filament to the Sun. This imaginary line should pass more or less through the oil-spot – see Figure 1. If the filament is fairly straight, then it should be roughly parallel to the sheet of paper. You could co-opt a second person to hold the sheet, otherwise some kind of support frame will have to be used.

You will also need a means of measuring the distance from the oil-spot to the filament when the oil-spot looks the same brightness as the surrounding paper. This distance will certainly not exceed 200 mm. Because the filament is somewhat inaccessible, we expect no great accuracy here.

The only other things you will need are

- these activity notes
- your activity notebook, plus something to write with
- a sky no more than partly cloudy, preferably within an hour of noon so that the Sun is about as high in the sky as it gets on any particular date.

Making measurements

Arrange the bulb, the sheet of paper and yourself as in Figure 1. In your activity notebook write down the date and time, whether the sky is clear (between any clouds) or hazy, the location of your observing site, details of your set-up, including the wattage of the bulb, and details of your technique, including how you will measure the distance between the oil-spot and the filament.

Vary the distance between the bulb and the sheet, keeping the sheet roughly perpendicular to the straight line from the filament to the oil-spot to the Sun, until the oil-spot looks about as bright as the surrounding paper. If the sheet is too close to the bulb then the oil-spot will look brighter than the surrounding paper. If it is too far from the bulb, it will appear darker. If your oil-spot is much larger than about 4 mm, the colour difference between the bulb and the Sun will make the brightness comparison difficult – this is why the oil-spot has to be small.

When the brightnesses are equal, measure the distance between the oil-spot and the filament as best you can.

Write down the distance in your activity notebook. Then move the paper away from the bulb, and repeat the procedure, to obtain another value of the distance. Carry on until you have recorded about ten values. And that's the end of your measurements!

Data analysis

The first task is to reduce your ten or so values of distance to a single value with its uncertainty, i.e. $d_b \pm \Delta d_b$. To do this, follow the procedure in Section 3.1 of the *Observational activities* booklet.

The next task is to understand the relationship between the Sun's luminosity and that of the bulb. We start with Equation 3.10 in Chapter 3 of *An Introduction to the Sun and Stars*. The flux density on the paper due to the Sun is given by

$$F_{\odot} = L_{\odot}/(4\pi D_{\odot}^2) \quad (1)$$

where L_{\odot} is the Sun's luminosity, and D_{\odot} its distance from the paper. Likewise, the flux density on the other side of the paper due to the bulb is given by

$$F_b = I_b/(4\pi d_b^2) \quad (2)$$

where I_b is the bulb's luminosity, and d_b its distance from the oil-spot. The action of the oil-spot is such that if the oil-spot has the same brightness as the surrounding paper, then, to sufficient accuracy, the flux densities are equal (probably within $\pm 20\%$). In this case, from Equations 1 and 2,

$$L_{\odot}/(4\pi D_{\odot}^2) = I_b/(4\pi d_b^2)$$

and so

$$L_{\odot} = I_b(D_{\odot}/d_b)^2 \quad (3)$$

To sufficient accuracy, D_{\odot} is 1.50×10^{11} metres, I_b is the known wattage of the bulb, and you have measured the value of d_b . If there were no further considerations, then the Sun's luminosity could be calculated from Equation 3.

But there *are* further considerations!

Further considerations

- (i) First, the solar flux density will have been somewhat reduced by absorption and scattering in the Earth's atmosphere. If you chose a clear day, and made your measurements within about an hour of noon, then for the UK in February/March, the solar flux density will have been roughly halved. You should thus *double* your value of L_{\odot} to make a rough correction for this effect.
- (ii) Second, Equations 1 and 2 assume that the sources radiate uniformly in all directions, and that we are at large distances compared with the sources' dimensions. This is close to the truth for the Sun, but for the lamp it is likely to be a poor assumption. State whether your value of L_{\odot} has been made higher or lower by this assumption, but attempt no correction.
- (iii) Finally, there is a big correction that you really *have* to make. It arises largely from the spectral response of the radiation detector that you have been using – your eyes. The spectral response of the eye is shown in Figure 2a (see p. 55), along with the solar spectrum, and in Figure 2b along with the shape of the spectrum of a black body at about the temperature of the tungsten bulb filament. The correction arises because the eye responds to a larger fraction of the Sun's radiation than it does to that of the bulb. You can see this from the shaded areas in Figures 2a and 2b, which represent these fractions (on the simplifying assumption that the eye responds uniformly between 0.5 μm and 0.6 μm , and not at all outside this range).

If the eye responds to a fraction f_{\odot} of the Sun's luminosity, and to a fraction f_b of the electrical power put into the bulb, then Equations 1 and 2 become

$$f_{\odot}F_{\odot} = f_{\odot}L_{\odot}/(4\pi D_{\odot}^2)$$

and

$$f_bF_b = f_bI_b/(4\pi d_b^2)$$

and so, in place of Equation 3, we have

$$L_{\odot} = (f_b/f_{\odot}) I_b (D_{\odot}/d_b)^2$$

The value of the ratio (f_b/f_{\odot}) is approximately 0.45 for a 150 W tungsten bulb. The shaded areas in Figure 2 give a smaller ratio than this, but the shape of the spectrum of a tungsten bulb departs somewhat from the shape of a black-body spectrum, leading to a larger value of f_b than that implicit in Figure 2b. Indeed, the value of f_b would be even higher were it not for some of the electrical power put into the bulb being transferred to the air around the bulb and convecting away, rather than being radiated.

Putting these corrections (i) and (iii) together, we thus have

$$L_{\odot} = (2 \times 0.45) I_b (D_{\odot}/d_b)^2 \quad (4)$$

You can now find your value of L_{\odot} .

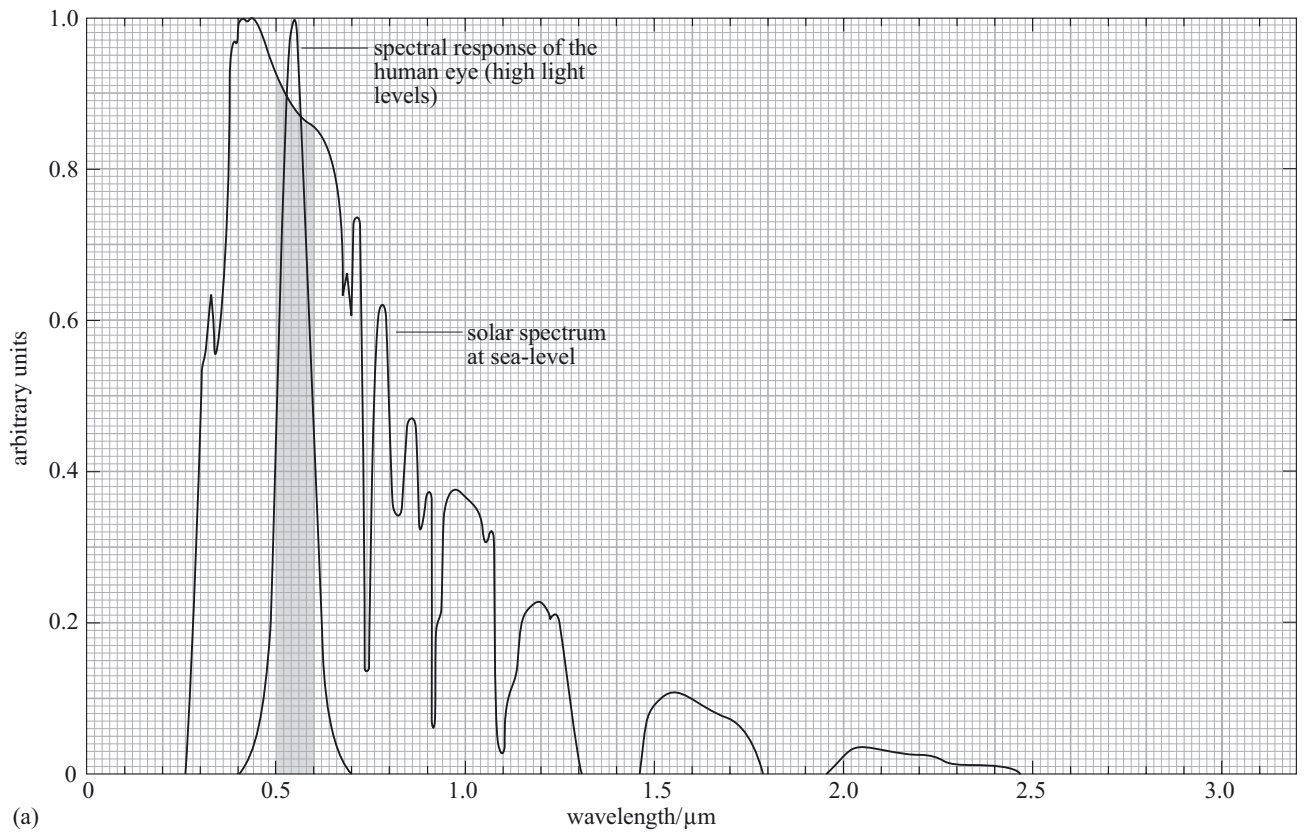
The uncertainty in your value is, at the very least, that arising from the uncertainty Δd_b in d_b . To find the corresponding uncertainty in L_{\odot} , substitute $d_b - \Delta d_b$ and $d_b + \Delta d_b$ for d_b in Equation 4, and hence you will obtain respectively $L_{\odot}(\text{max})$ and $L_{\odot}(\text{min})$ (remember that the larger the value of d_b the smaller the value of L_{\odot}). The uncertainty ΔL_{\odot} is then given by

$$\Delta L_{\odot} = (L_{\odot}(\text{max}) - L_{\odot}(\text{min}))/2 \quad (5)$$

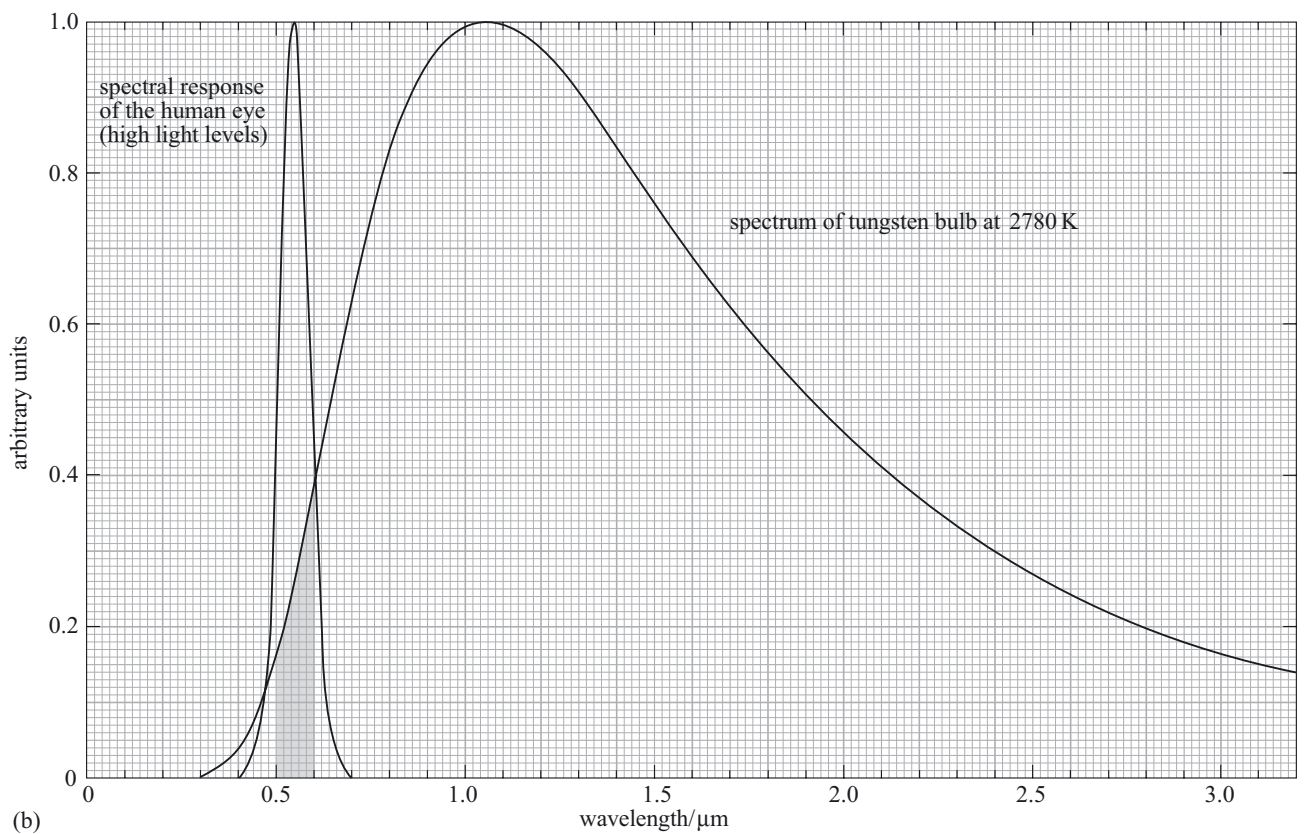
This is a lower limit to the uncertainty in L_{\odot} , because correction (ii) was not made, and because corrections (i) and (iii), which were made, carry their own uncertainties. However, it is sufficient for you to quote the lower limit to the uncertainty based on Δd_b , and leave it at that. Do, however, remember to state whether correction (ii) would have made your value of L_{\odot} higher or lower.

Conclusion

It is clear that your value of the Sun's luminosity will not be very accurate. Indeed, you could easily be out by a factor of two or more! But despite this inaccuracy, the activity does illustrate many of the problems that astronomers face in making measurements. Also, given the crudeness of the approach, it is quite something to get within even a factor of two!



(a)



(b)

Figure 2 The spectral response of the human eye, and: (a) the solar spectrum; (b) the spectrum of a tungsten bulb (at 2780 K), assuming the spectrum of the tungsten bulb to have the shape of the spectrum of a black body.

Glossary for the observational activities

altitude The angle between an observer's horizontal plane and the direction to a celestial body, measured along the great circle that passes through the zenith.

angular magnification The factor by which the angular size of an object is increased when viewed through an optical instrument.

aperture The diameter of the light-gathering entrance to an optical instrument. For binoculars, it is the diameter of the big lenses in the front.

best fit A line on a graph that passes closest to the greatest number of data points. Such a line is obtained by an exact mathematical procedure, but can often be estimated well enough by 'hand and eye'.

celestial equator The projection, from the centre of the Earth, of the Earth's Equator on to the celestial sphere.

celestial sphere A sphere, larger than the Earth, centred on the Earth's centre.

constellation Any one of the 88 contiguous, irregular regions into which the whole celestial sphere is divided.

declination Celestial latitude, extending north and south of the celestial equator from 90° N at the north celestial pole to 90° S at the south celestial pole.

ecliptic The great circle formed by the intersection of the ecliptic plane with the celestial sphere: the path of the Sun across the celestial sphere.

ecliptic plane The orbital plane of the Earth.

error bars Lines attached to each data point on a graph to show the uncertainty in the value of the point.

field of view The angle across the view seen through an optical instrument.

First Point of Aries The point on the celestial equator where the Sun's declination changes from south to north. It is chosen as the zero of right ascension.

great circle Any line on a sphere that is the intersection between the sphere and a plane passing through its centre.

librations The apparent oscillations of the side of the Moon that faces the Earth, that allow us to see about 59% of the lunar surface.

light-gathering power A measure of the fraction of the light emitted by an object that is gathered by an optical instrument.

mean solar day A fixed length of time, equal in duration to the mean length of the solar day.

mean value The sum of n values of a quantity, divided by n . It is the most common type of average.

meridian The great circle that passes through the celestial poles and an observer's zenith.

north celestial pole The projection, from the centre of the Earth, of the Earth's North Pole on to the celestial sphere.

planisphere A printed map of the sky with a rotatable aperture that shows which half of the celestial sphere is above an observer's horizon at any particular date and time.

precession The cyclical motion of the rotation axis of a body which does not have a perfectly spherically symmetric mass distribution (e.g. the 'wobble' of a spinning top). The Earth's axis of rotation exhibits precession, with the direction of the celestial pole tracing out a circle on the celestial sphere every 25 800 years.

prograde Any rotatory motion in the Solar System that is anticlockwise when viewed from above the North Pole of the Earth.

random error An uncertainty in a quantity revealed by the different values obtained when the quantity is measured in the same way several times.

retrograde Any rotatory motion in the Solar System that is clockwise when viewed from above the North Pole of the Earth.

right ascension Celestial longitude, measured eastwards along the celestial equator from 0 hours (First Point of Aries) to 24 hours.

sidereal day The period of one rotation of the Earth with respect to the distant stars. It is slightly shorter than the solar day.

solar day The period of rotation of the Earth with respect to the Sun. The period varies slightly with the position of the Earth in its orbit.

south celestial pole The projection, from the centre of the Earth, of the Earth's South Pole on to the celestial sphere.

standard deviation A measure of the spread of values in a data set.

synchronous rotation When a body rotates on its axis in the same time and in the same direction as it orbits another body. The Moon is in synchronous rotation with respect to the Earth.

systematic error A bias towards values of a quantity that are either too high or too low, resulting from inadequacies in the equipment or in the measurement procedure.

uncertainty A reasonable estimate of the amount by which the true value of a quantity differs from the true or (mean) value obtained by measurement.

zenith The projection, from the centre of the Earth, of an observer's position on to the celestial sphere. For the observer the zenith is directly overhead.

